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ENGINEERING DESIGN HANDBOOK

GRENADES (U)

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ENGINEERING DESIGN HANDBOOK

GRENADES (U)

This pamphlet is published for the information and guidance of all concerned.

(AMCRD-R)

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PREFACE

The Engineering Design Handbook Series of the Army Materiel Command is a coordinated series of handbooks containing basic information and fundamental data useful in the design and development of Army materiel and systems. The handbooks are authoritative reference books of practical information and quantitative facts helpful in the design and development of Army materiel so that it will meet the tactical and the technical needs of the Armed Forces.

This handbook on *Grenades* has been prepared as an aid to scientists and engineers engaged in military research and development programs, and as a guide and ready reference for military and civilian personnel who have responsibility for the planning and interpretation of experiments and tests relating to the performance of military materiel during design, development and production.

The text and illustrations were prepared by Lino-Tech, Incorporated, for the Engineering Handbook Office of Duke University, prime contractor to the Army Research Office-Durham. Many valuable suggestions were made by personnel from Picatinny Arsenal, Edgewood Arsenal, and the U. S. Army Harry Diamond Laboratories.

Comments and suggestions on this handbook are welcome and should be addressed to Army Research Office-Durham, Box CM, Duke Station, Durham, North Carolina 27706.

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CHAPTER 1 (U)

INTRODUCTION

1—1 (U) PURPOSE OF HANDBOOK

This handbook provides data that the grenade designer can use to develop a munition that will meet the general requirements prescribed by the Army. Design data are presented for both hand grenades and rifle grenades. Rifle grenades are now obsolete, however, the data are presented for historical reasons, completeness, and, perhaps, use at some later time. The design of self-propelled grenade-type projectiles, such as rocket grenades and their associated launching devices, are beyond the scope of this handbook because these self-propelled "grenades" are generally considered to be in the rocket or missile category.

1—2 (U) GENERAL

A grenade is a small munition for close-range infantry combat within the range of mortar fire. Among all of the weapons used in infantry combat, grenades have a unique position because they are the individual infantryman's area-fire weapon of opportunity. All other forms of area-fire weaponry are normally controlled by unit leaders or others higher in the chain of command than the individual infantryman. Hence, grenades provide an area-fire capability at the very lowest level, and they can be brought to bear on an enemy much more quickly than any other area-fire weapon.

1—2.1 (U) GRENADE PAYLOADS

The payload of a grenade may be broadly classified as either explosive or chemical. Each of these classifications may be broken down further, as described in the paragraphs which follow.

1—2.1.1 (U) Explosive Grenades

Explosive grenades are either of the fragmentation-type, the blast-(offensive) type, or the shaped-charge type. Fragmentation grenades are used primarily to inflict personnel casualties, and, therefore, are designated as antipersonnel (APERS) grenades. Fragmentation grenades can also be used against materiel, but their effectiveness is limited in this application.

A blast, or offensive, grenade produces no fragments (except the metal parts of the fuze) when it detonates. Its antipersonnel effects result exclusively from blast and are significantly less than those of fragmentation grenades. Blast grenades have been used in the past for very close combat in the open and for attacking enemy personnel in lightly structured buildings or similar structures. Blast grenades were developed primarily to protect the thrower from fragments in these close combat situations. However, control of fragmentation pattern of present-day fragmentation grenades and appropriate training of the users minimize the danger to the thrower. Therefore, blast grenades are obsolete.

Shaped charge explosive grenades are used primarily to defeat armored vehicles. The antipersonnel effects of this type of grenade are limited by specified military requirements. However, antipersonnel effectiveness can be provided if required.

1—2.1.2 (U) Chemical Grenades

The three basic types of chemical grenades in use are: (1) irritant, (2) incendiary, and (3) smoke.

Irritant grenades are used to harass or incapacitate enemy personnel. They are also used for riot control.

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Incendiary grenades contain chemicals that burn with a very high temperature. They are used primarily for destroying equipment.

Smoke grenades are used for screening and for signaling. The payload may be a chemical that produces white smoke, which is normally used for screening, or it may be a chemical that produces colored smoke, which is normally used for signaling.

1—2.2(U) GRENADE PROJECTION

The methods of projecting grenades provide the means for classifying the two main types of grenades; namely, hand grenades and rifle grenades. A hand grenade, as its name implies, is thrown by hand, without the use of any auxiliary equipment. Similarly, a rifle grenade is fired from an infantry rifle. To fire a rifle grenade, however, an adapter, or auxiliary barrel, must be attached to the rifle. Furthermore, a *special blank cartridge must be used to propel the grenade.* The use of ball or AP ammunition is likely to detonate the grenade, killing the grenadier.

Any hand grenade can be converted to a rifle grenade by the use of a special grenade adapter. Conversely, some rifle grenades may be used as hand grenades, particularly those with chemical payloads.

Hand grenades, while normally projected by throwing, must be capable of being rigged as a booby trap. Strictly speaking, booby trapping is not a method of projection; nevertheless, the ability of a hand grenade to be used as a booby-trap device is a major design requirement for many hand grenades.

1—3(U) HISTORY

Grenades have been part of the weapons mix in infantry forces for centuries [1*]. They were developed in the 15th Century, and were used in many wars down through the years, including the Civil War and Russo-Japanese War (1904). It was not until World War I, however, that well-designed grenades, capable of being mass-produced, were developed. During World War I, both sides used grenades in large quantities to support their trenchline raids against one another. Also, it was during this war that the rifle grenade evolved into a practical and useful infantry weapon.

Grenades were used extensively during World War II, particularly in actions such as the hedgerow fighting in Normandy. A weapons evaluation of the Korean Conflict indicates that the grenade was one of the major weapons, and that almost all "in-fighting" against Communist forces was attended by hand-grenade action [2*].

Grenades have been a particularly useful weapon in guerrilla-type wars, such as the Indo-China War and the Viet-Nam War. Guerrilla warfare is often fought at distances within the minimum range of artillery and mortars, and fragmentation grenades become the main source of area-fire.

There is still a marked physical resemblance between World War I grenades and present-day grenades. However, over the years, there have been great advances in grenade safety, reliability, and effectiveness. For example, the fragmentation pattern, and the size of fragments, can now be predicted and controlled to a reasonable degree. Electrical fuzing is used in some types of rifle and hand grenades. Furthermore, some rifle grenade fuzes employ an out-of-line, or interrupted, explosive train for safety; these fuzes rotate the explosive train into alignment by sensing, or recognizing, the firing environment.

Rifle grenades, although they have been improved greatly over the years, still possess certain inherent tactical limitations. Their effective range is limited to, at most, 200 yards, and they are relatively inaccurate. Furthermore, they require the use of special adapters and sights that must be attached to the rifle before the grenade is fired. Because of these limitations, rifle grenades are now being replaced by weapons such as the antitank M72 HEAT rocket and the antipersonnel M79 40 mm grenade launcher. Both of these

*Superscript numbers refer to References at the end of each chapter.

weapons, while not actually rifle grenades, perform the same functions, and are more effective and reliable. Since the 40 mm is essentially a grenade-type weapon system, a brief description is given below.

1—4 (U) 40 mm GRENADE SYSTEMS [3]

1—4.1 (U) MATERIEL AND PURPOSE OF SYSTEM.

The 40 mm Grenade Systems include the following items:

(a) 40 mm Grenade Launcher, M79

(b) 40 mm Grenade Launcher, XM148

(c) Cartridge, Grenade, 40 mm, HE, M406

(d) Cartridge, Grenade, 40 mm, Practice, M407

The systems are provided for defensive and offensive use by small units or individual combatants. They provide effective area target fire coverage in the range zone of 30 meters to 350 meters. This is the area between the maximum throwing range for the hand grenade and the minimum range for mortar fire. They are suitable for direct firing against vertical targets such as openings in buildings, cave entrances and bunker apertures at ranges of 30 meters to 150 meters. For area fire they can be used at ranges of from 30 meters to 400 meters maximum range. Each of the system components is described in the paragraphs which follow.

1—4.2 (U) GRENADE LAUNCHER, M79.

The M79 Launcher as shown in Fig. 1—1 is simple in design and construction. Basically, it is a single-shot, shoulder-fired, shotgun type of weapon, with break-open action. Its nominal caliber is 40 mm. The weight of the projector, without cartridge, is 6 lb; loaded, its weight is 6.5 lb. The overall length is 28.625 in. The length of the barrel is 14.71 in. The forward 12 in.

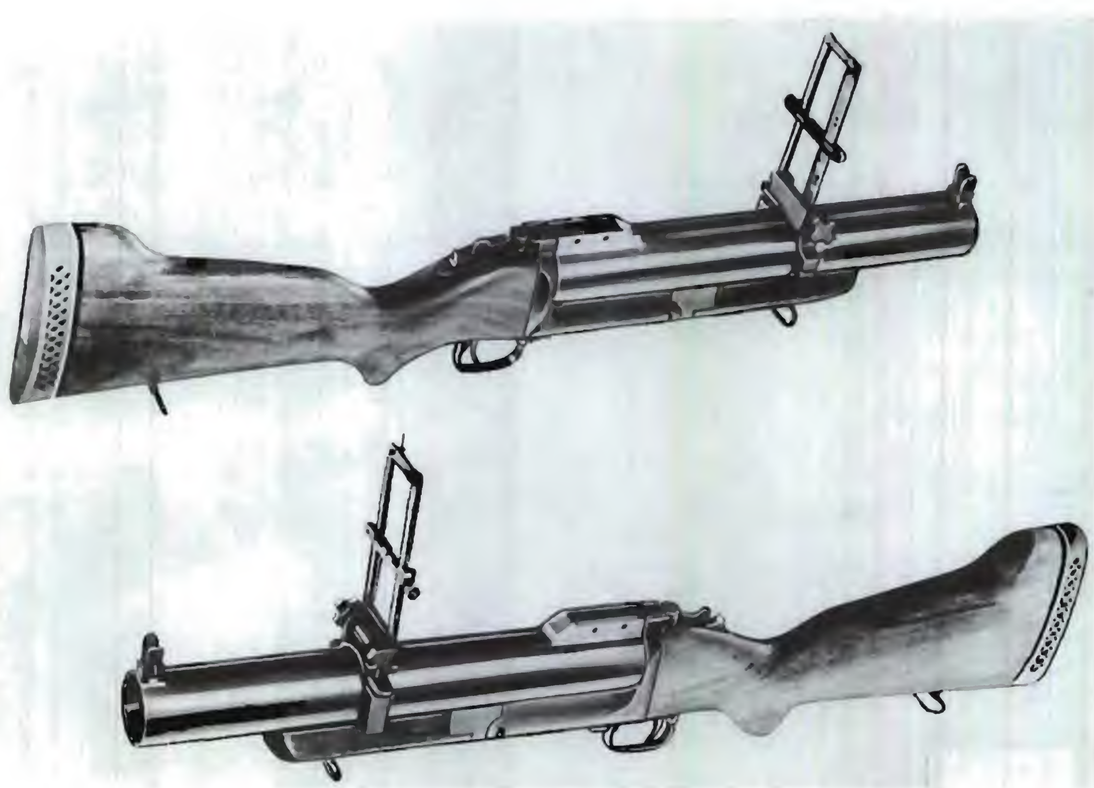

FIGURE 1 — 1 (U) — GRENADE LAUNCHER, 40 MM, M79

of the barrel are rifled, with 6 rifling grooves 0.01 in. deep, of uniform twist, right hand; one turn in 48 inches.

1—4.3(U) GRENADE LAUNCHER, XM148

The XM148 Launcher shown in Fig. 1—2 has the same capability as the M79 Launcher, but is designed for use on the M16 Rifle. It is attached to the rifle by means of a special handguard. The standard rifle handguard is removed from the rifle and replaced with the spiral handguard to which the launcher has been fixed. It is expected that the launcher, when once attached, will remain as a fixed part of the rifle.

The length of the barrel in this configuration is 10 in., 4.71 in. shorter than the barrel length of the M79 Launcher. The rifling has the same characteristics as that of the M79 Launcher, but the rifled length is correspondingly shorter. The shorter length barrel results in a reduction of the standard muzzle velocity from 250 ft per sec to 245 ft per sec, and spin from 3750 rpm to 3675 rpm, but the maximum range is maintained at 400 meters. The weight of the rifle and launcher assembly--loaded with a magazine of ball ammunition and one grenade--is approximately 11 lb.

1—4.4(U) CARTRIDGE, GRENADE, 40 mm, HE, M406

The M406 Cartridge shown in Fig. 1—3 is a complete round assembly weighing 8 oz, and the overall length is 3.9 in. Its components are an aluminum cartridge case M118, with percussion primer M42 and propellant charge, and projectile (M406) with explosive filler and point-detonating fuze M551. The projectile also includes a windshield of ogival shape covering the fuze. The weight of the projectile assembly as it leaves the muzzle is 6 oz (0.375 lb) and the length is 3.1 in.

The propelling charge of approximately 365 mg of M9 propellant is contained in a brass cup, which in turn is held in a retainer which surrounds the cup and is provided with holes in the forward portion. The cartridge employs the high-low propulsion system in which the gas output of the propellant is confined, temporarily, at high pressure in the brass propellant cup and retainer. The pressure, approximately 35000 psi, ruptures the brass cup through the holes in the retainer, and the propellant gas then expands into the free space of the cartridge case, creating a chamber pressure of about 3000 psi. The pressure acting on the grenade to accelerate it through the launcher bore is the lower pressure. Since the force exerted by the projector against the man firing it is proportional to the force acting on the grenade, the advantage of the high-low system is evident.

The projectile for the M406 Cartridge is a 40 mm caliber antipersonnel, high explosive, fragmentation grenade. Its overall length, including the ogival windshield, is

FIGURE 1—2(U)—XM16E1 RIFLE WITH GRENADE LAUNCHER, 40 MM, XM148

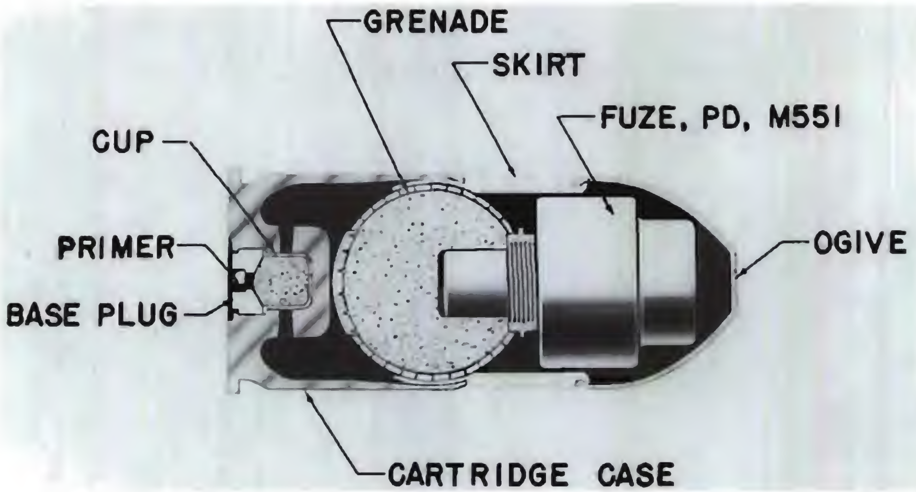

FIGURE 1—3(U)—CARTRIDGE, GRENADE, 40 MM, HE, M406

3.1 in., and the weight is 6 oz. The bursting charge is 1.25 oz of Composition B. The grenade body is formed of notched, rectangular steel wire. Upon detonation, the notched wire of the grenade body breaks into highly lethal fragments. The grenade has an effective casualty radius (the radius of a circle about the point of detonation in which normally we may expect 50% of the exposed personnel to become casualties) of 5 meters.

The M551 Point-Detonating Fuze is armed by the combined action of setback and centrifugal forces. With this fuzing, the grenade will remain unarmed for about 0.25 sec after firing. Thus accidental impacts or short flights--under 18 meters from the launcher--should not result in functioning of the grenade. Arming is assured after 27 meters of flight.

1—4.5(U) CARTRIDGE, GRENADE, 40 mm, PRACTICE, M407

The M407 Cartridge is a complete round assembly designed to be safe to fire for practice purposes which yields spotting signature of the point of impact of the grenade. Essentially the same components are used as for the M406 Cartridge, except that the grenade is inert loaded to weight and is provided with a spotting charge of about 2 g of yellow smoke powder. The smoke cloud can be detected from the firing position at maximum range. The ballistic performance and fuze action exactly duplicate those for the M406 Cartridge.

(U) REFERENCES

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2. S. L. Marshall, *Infantry Operation and Weapon Usage in Korea*, Report ORU-0-13, Operations Research Office, Johns Hopkins University, Silver Spring, Md., 27 October 1951.
3. TM 9-1330-200, *Grenades, Hand and Rifle*.

CHAPTER 2 (C)

HAND GRENADES

SECTION I (U)

GENERAL

2—1 (U) PURPOSE

A hand grenade is a small, relatively lightweight weapon used for close combat, generally within a maximum range of about 40 meters. The most common use of hand grenades is to inflict personnel casualties on the enemy. For this purpose, high explosive fragmentation-type hand grenades are used almost exclusively.

Hand grenades are also used for harassing the enemy, for signaling and screening, and for incendiary use. For these purposes, chemical hand grenades are used.

2—2 (U) TYPICAL HAND GRENADE REQUIREMENTS

Each type of hand grenade is designed to meet certain specific requirements with respect to lethality, size, weight, etc. It is desirable that military requirements and characteristics be so specified as to give the designer-developer maximum flexibility in achieving a most nearly optimum design. Historically, military requirements, in the effectiveness area, have been specified in terms of effects against a specific test arena which is not necessarily representative of combat usage of the item and may not be conducive to the optimum design. Military effectiveness requirements should be specified in terms of specific targets, with description of such targets; the frequency of engagement of each specified target; and the distribution of ranges at which each specified target is engaged. Relative to safety of the thrower, the military requirement should specify the level of risk which is acceptable; for example, "the probability that the thrower will be hit with an injurious fragment shall be less than 1 in 100,000" and description of the position of the thrower; for example, "prone man in winter clothing with average terrain cover". Also, to the extent possible, physical characteristics should be general with only the maximum specified; that is, maximum weight, maximum size, etc. However, all hand grenades must meet the following general requirements:

a. Be operable over a temperature range of -40° to +125°F at any humidity level.

b. Be operable after prolonged storage in a packaged state at temperatures between -65° and +160°F at any humidity level. However, the low-temperature storage limit for some types of chemical-type grenades may be -40°F.

c. Be operable after being subjected in a packaged state to the atmospheric pressure variations, shock, and vibration encountered during air transport.

d. Be operable after being subjected to the shock and vibration encountered during truck and rail transport, whether transported in an unpacked or packed state.

e. Be waterproof.

f. Be operable after being dropped by parachute. Should the parachute fail to open, they must remain safe for disposal.

g. Be simple to operate under all combat conditions by personnel having minimum instruction.

h. Be safe.

i. Meet requirements of MIL-STD-331.

2—3(U) GENERAL TEST SPECIFICATIONS

There are many standard military specifications that prescribe test procedures for determining if a hand grenade meets the general requirements of par. 2—2. For example, specifications for immersion testing may be used to determine if the grenade is waterproof. Or, specifications for transportation vibration testing may be used to determine if the grenade can withstand the rigors of truck transport.

There are also standard military specifications for testing grenade components. For example, MIL-STD-331, Test No. 105, "Temperature and Humidity", provides methods of testing a fuze for its resistance to temperature and humidity extremes, while Test No. 115, "Static Detonator Safety", provides methods of testing for detonator safety.

The design specification for a grenade will usually specify the test specifications that must be used in the design of a particular grenade. In some cases, only the requirements will be specified, and the designer will have to determine which specifications must be used to determine if the requirements are met. In either case, the designer must keep the requirements in mind from the very beginning of a project to the end, and should continually consult the test specifications to insure that his design can meet the test requirements.

SECTION II (C)

FRAGMENTATION HAND GRENADES

2—4(U) GENERAL

This section describes the military requirements specified for a fragmentation hand grenade. Following this, the design considerations involved in meeting these requirements are discussed, and a typical design approach is illustrated.

2—5(U) REQUIREMENTS

In addition to the requirements specified in par. 2—2 for all hand grenades, a fragmentation hand grenade must meet certain operational requirements. These requirements, which are normally given in the design specifications for the grenade, are discussed briefly in the paragraphs which follow.

2—5.1(U) FRAGMENTATION PATTERN

The required spatial distribution of fragments will be given in the design specification. Since it is impossible to predict a hand grenade's orientation with respect to the target at the time of detonation, ideally, the grenade should produce a uniform spatial distribution of fragments. However, because of certain practical factors, which are discussed later, a uniform spatial distribution is impossible to attain. Therefore, for all present-day fragmentation grenades, a nearly uniform spatial distribution is required, and can be attained. A nearly uniform spatial distribution provides reasonable assurance that a target within the fragmentation range of the grenade will be hit by fragments.

2—5.2(U) LETHALITY

The lethality of a grenade is a measure of the grenade's ability to incapacitate an enemy. In this sense, incapacitation means either to kill him or to severely wound him so that he cannot fire a weapon or offer effective resistance.

2—5.2.1(U) Incapacitation Time

A requirement for fragmentation grenades is that they incapacitate an enemy within a certain time. Since hand grenades are used for close combat, this time must

be very short; for present-day grenades, it is usually immediate or at most 5 sec.

2—5.2.2 (U) Effective Area

The design specification will contain a requirement that the hand grenade fragments must be lethal to specified damage level out to a certain distance and safe to the thrower beyond a second specified distance. The effective area is normally expressed as a circular area about the point of burst within which a specified average probability of incapacitation of a specific target is attained. The safe distance is generally associated with the throwing range of the grenade by a typical soldier. Sound training techniques assist in assuring that the thrower will not be incapacitated by his own item.

2—5.2.3 (U) Effectiveness Criterion

The effectiveness criterion of a fragmentation hand grenade is a measure of the grenade's capability for incapacitating an enemy within the effective area of the grenade and within the specified incapacitation time. The effectiveness requirement is normally expressed as the probability that the target will be incapacitated within a specified time period.

Since the study of wound ballistics is a specialized field in itself, the grenade designer will normally require pertinent data relating to fragment lethality. The U.S. Army Ballistic Research Laboratories possess the latest information in this regard.

2—5.3 (U) SIZE, WEIGHT, AND SHAPE

The shape of a hand grenade whether it is spherical, cylindrical, or barrel-shaped has little effect on the distance a grenade can be thrown or on how accurately it can be thrown. However, the size and weight of the grenade greatly affect these two parameters. If the grenade is too large, or too small, it cannot be gripped properly by the thrower, and therefore, both distance and accuracy will be degraded. If a grenade is too heavy, obviously it cannot be thrown the desired distance or thrown very accurately. The same is true if the grenade is too light, in which case, distance and accuracy are affected by wind forces.

The size, weight, and shape requirements for a hand grenade are usually given in the design specification, and are specified in a manner that provides some leeway for the grenade designer. For example, a maximum weight for the grenade is normally specified rather than a precise weight. A typical design specification may state that the grenade should be as light as practical, but shall not exceed 16 oz. Similarly, maximum dimensions are usually specified. For example, if the grenade is to be spherical, its maximum diameter will be specified, which, typically, is about 3 in. If the grenade is to be barrel-shaped, the length of its longest axis will be specified, which, typically, is about 4-1/2 to 5 in.

2—5.4 (U) SAFETY

Safety requirements for the grenade will be given in the design specification. Typical requirements are:

(1) The thrower must perform some type of positive action to cause the grenade to arm after it is released. For example, for a fragmentation grenade to become armed, two separate actions must occur, namely: the thrower must first pull a safety pin out of the grenade and then release a safety lever when he throws the grenade.

(2) A time delay must be incorporated into the fuze so that the fuze will not initiate detonation until about 4 or 5 sec after the grenade is thrown.

(3) To protect the thrower, the number of incapacitating fragments must be minimum beyond a specified distance from the point of detonation. For a typical fragmentation hand grenade, this distance is about 60 ft.

(4) If the hand grenade is designed for impact function, it must not detonate immediately if dropped by the grenadier in the act of throwing. Immediate detonation

can be avoided by incorporating a delay-after-arming feature into the fuze. Typically, this delay time is 1 sec, since a grenade dropped from raised-arm height will impact the ground in less than this time.

2—5.5 (U) FUZING

The design specification for a fragmentation grenade will specify the manner in which detonation should be initiated, i.e., after expiration of a fixed time after final arming or upon impact with the ground. Practically all present-day grenades use time fuzes, i.e., nonimpact, and these fuzes are required to detonate the grenade approximately 4.5 sec after the grenade is thrown.

If the specification specifies an impact-type fuze, it most likely will also call for an overriding time-function feature. This ensures that the grenade will detonate after a certain specified time should it fail to detonate on impact.

2—6 (C) DESIGN CONSIDERATIONS

To meet the requirements specified for a proposed fragmentation grenade, various design parameters must be determined and controlled. During the initial design stages, these parameters may be determined analytically using the design formulas given in the paragraphs which follow. These formulas are generally accurate enough for preliminary design; however, the optimum design parameters can only be determined empirically, based on the results of fragmentation tests of developmental grenades[2].

2—6.1 (C) LETHALITY

2—6.1.1 (C) Lethality Criterion

The lethality criterion for a fragmentation grenade is based on the probability that a random hit on a man will completely incapacitate that man within a specified time period. This time period is usually immediate or at most 5 sec.

Precise wound ballistic data and cover function data are needed to design a grenade with fragments having a particular probability of incapacitation as a function of time and mission. These data are available at the U.S. Army Ballistic Research Laboratories (BRL), Aberdeen Proving Ground, Md., and are being updated continually. Reports BRL R 1269 and BRL MR 1203 provide the most recent wound ballistic data and cover function data, respectively. However, because the data are being updated continually, the grenade designer should contact BRL for the most recent data at the start of a project.

Probabilities of incapacitation of single fragments conditioned on a hit (P_{hk}) are given in BRL MR 1209 as a function of mass and striking velocity. The form of the relation is:

$$P_{hk} = 1 - e^{-a(mv_s^{3/2} - b)^n} \tag{2—1}$$

where

m = mass of fragment, grains
v_s = striking velocity of fragment, fps
a, b, n = experimentally derived constants

The constants — a, b and n — for various stress levels and wounding times are given in BRL MR 1269.

2—6.1.2 (C) Number of Incapacitating Fragments

For a small target located at a certain distance from the point of burst, the expected number of incapacitating fragments $N_k(r)$ of a given mass is given by the expression:

$$N_k(r) = \frac{A_T N_m P_{hk}}{\Omega r^2} \tag{2—2}$$

where

A_T = target area exposed to burst, sq ft

N_m = total number of fragments of a given mass

P_{hk} = conditional probability that a random hit on the target will incapacitate the target

Ω = solid angle throughout which the fragments are projected. (For a spherical grenade, Ω would have a value of 4π.)

r = distance from point of burst to target, ft

The probability $P_k(r)$ that the target at range r from ground zero will be incapacitated is:

$$P_k(r) = 1-e^{-N_k(r)} \tag{2—3}$$

In Eqs. 2—2 and 2—3 it is assumed that all fragments travel in a straight line, which is usually an acceptable assumption over the range that the fragments are effective.

2—6.1.3 (C) Lethal Area [5,6]

Because hand grenades are unstabilized in flight and are usually time fuzed, their orientation with respect to the target at time of burst cannot be predicted. Ideally, then, the fragments should be uniformly distributed in every direction about the grenade. A spherical grenade would provide the most uniform distribution pattern; but, for purposes of gripping and throwing, fragmentation hand grenades are usually barrel-shaped (par. 2—5.3).

The ideal fragmentation pattern — i. e., fragments distributed uniformly in every direction about the grenade — is impractical to achieve in a barrel-shaped grenade. In fact, it is impossible to achieve this in a grenade of any shape, even spherical, because space taken by the fuze and the load opening will interfere with fragment distribution. A typical fragmentation pattern for a barrel-shaped grenade is shown in Fig. 2—1. The vertical burst (long axis vertical) produces a higher lethal area than the horizontal burst (long axis horizontal), but the grenade will most likely settle in a horizontal position on level terrain. It can be seen that, in the horizontal burst position, there are a number of blind spots in the fragmentation pattern. While a preliminary design may be based on achieving a uniform fragmentation pattern, fragmentation tests must be performed to determine the actual fragmentation pattern. Once the actual number, mass, spatial distribution, and initial velocity of individual fragments are determined by experimental firings, the actual lethal area of the grenade can be calculated.

Lethal area is often used as a criterion for evaluating the overall effectiveness of a fragmentation grenade. Lethal area is generally computed using a high speed digital computer. BRL TN 1510 describes lethal area in detail. Lethal area A_L is defined as:

$$A_L = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P_k(x, y)\ dx\ dy \tag{2—4}$$

where $P_k(x, y)$ is the probability of incapacitation of a target located at x and y relative to munition ground zero. Lethal area is not a physical area but rather a weighted area where each differential area is weighted by the probability of incapacitation. Lethal area is proportional to the expected number of casualties produced by a munition.

2—6.2 (C) FRAGMENTATION CONSIDERATIONS [4]

From Eq. 2—1, it can be seen that the lethality of a fragmentation grenade P_{hk} depends upon the mass and presented area of any fragment, and the velocity at which the fragment strikes the target. The values

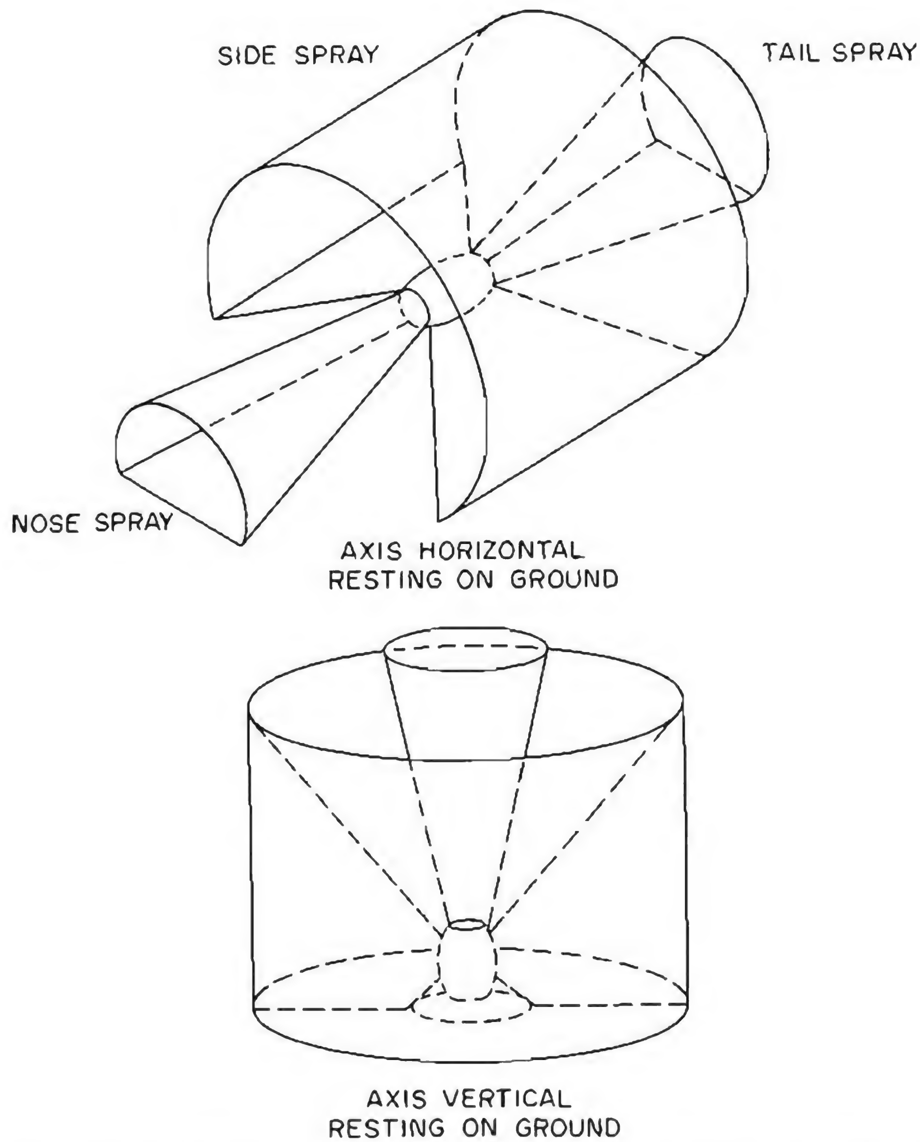

FIGURE 2—1(U)—FRAGMENTATION PATTERN FOR A TYPICAL FRAGMENTATION HAND GRENADE

of these parameters are, in turn, determined by the mass distribution of fragments, the dimensions of the grenade casing and the material from which it is made, the type and weight of the grenade explosive, and the initial velocity of the fragments at the time of burst.

By the use of the mathematical relationships between these criteria, the proper fragmentation casing can be designed to give the required number of lethal fragments. Early grenades were made with solid fragmentation casings that relied on *natural* fragmentation characteristics. Today's grenades are based on techniques that permit *controlled* fragmentation (par. 2—8.4). However, although a fragmentation casing can be constructed to give a *probable* fragment mass, quantity, and distribution, the controlled fragment characteristics of the casing should be reasonably close to its natural fragmentation characteristics in regard to average fragment mass so that there will be a higher degree of reliable performance. As a method, the grenade can be designed by considering its natural fragmentation

probabilities, and then applying controlled fragmentation methods to assure reliable performance. The paragraphs which follow give the design criteria as related to natural fragmentation. Their relationship to controlled fragmentation is covered in par. 2—8.4.

2—6.2.1 (C) Mass Distribution of Fragments

Fragmentation grenades are considered as having thin-walled casings. If it is assumed that fragmentation from a thin-walled casing is the result of two-dimensional breakup[7], the total number of fragments N_m having a mass greater than m can be expressed as

$$N_m = \frac{M}{2\mu} e^{-\left(\frac{m}{\mu}\right)^{1/2}} \qquad (2\text{—}5)$$

where

M = total mass of grenade casing

μ = fragmentation efficiency of the grenade (par. 2—6.2.2)

The term $\frac{M}{2\mu}$ represents the total number of fragments N_T (par. 2—6.2.2); therefore, Eq. 2—5 may be written as

$$N_m = N_T e^{-\left(\frac{m}{\mu}\right)^{1/2}} \qquad (2\text{—}6)$$

2—6.2.2 (C) Fragmentation Efficiency μ

For a given fragmentation grenade, the quantity μ is dependent upon the characteristics of the explosive, the characteristics of the grenade casing, and the physical dimensions of the casing. The term μ can be used as an efficiency factor because 2μ is actually the arithmetic average fragment mass. Since 2μ represents the arithmetic average fragment mass, it can be used to determine the total number of fragments N_T as follows:

$$N_T = \frac{M}{2\mu} \qquad (2\text{—}7)$$

2—6.2.2.1 (C) Scaling Formulas for μ

Either of two formulas may be used to account for the dependency of μ upon the physical dimensions of the grenade casing and upon the explosive used. The formulas, given in the paragraphs which follow, are in good agreement for small values of the explosive charge-to-casing mass ratio.

2—6.2.2.2 (C) Mott Scaling Formula[8]

The following formula relates the value of μ to the inside diameter and thickness of the casing:

$$\mu^{1/2} = B^{5/6} d_i^{1/3} \left(1 + \frac{t}{d_i}\right) \qquad (2\text{—}8)$$

where

B = a scaling constant depending upon the explosive and the physical characteristics of the casing material

d_i = inside diameter of casing, in.

t = thickness of casing, in.

2—6.2.2.3 (C) Gurney-Sarmousakis Scaling Formula[9]

The following formula relates the value of μ to the inside diameter of the casing, to the thickness of the casing, and to the explosive charge-to-casing mass ratio:

$$\mu^{1/2} = D \left[\frac{t(d_i + t)^{3/2}}{d_i}\right] \sqrt{1 + 1/2\ (C/W)} \qquad (2\text{—}9)$$

where D = a scaling factor depending upon the explosive and the physical characteristics of the casing material

t = thickness of casing, in.

d_i = inside diameter of casing, in.

C = weight of explosive charge, grains

W = weight of fragmenting metal, grains

2—6.2.2.4(C) *Effect of Explosives on* μ [10]

From Eqs. 2—8 and 2—9, it can be seen that the value of $\mu^{1/2}$ is dependent upon the explosive used in the grenade. The results of a series of test firings to determine the fragmentation efficiency of various explosives are given in Table 2—1. While the test specimens were not fragmentation grenades, the test results clearly indicate the variation in the value of μ for various types of explosives.

2—6.2.3(C) Velocity of Fragments

The probability of incapacitation P_{hk} is dependent upon the velocity at which the fragment strikes the target (Eq. 2—1). The striking velocity v_s is, in turn, dependent upon the distance from the point of burst, air density, and various fragment parameters.

TABLE 2-1(C). EFFECT OF EXPLOSIVES ON μ [10]

Explosive *	Cylinder Thickness, t (in.)	Inside Diameter, d_i (in.)	C/W	$\mu^{1/2}$	Mott scaling constant (B)	Gurney-Sarmousakis scaling constant (D)
Cast explosives						
Baratol	0.254	2.000	0.562	1.237	2.73	2.55
Comp B	0.253	1.999	0.377	0.532	1.18	2.14
Cyclotol (75/25)	0.253	1.999	0.380	0.471	1.05	1.01
H-6	0.254	1.999	0.395	0.666	1.47	1.34
HBX-1	0.255	1.999	0.384	0.615	1.36	1.30
HBX-3	0.255	1.999	0.403	0.781	1.72	1.65
Pentolite (50/50)	0.254	1.999	0.366	0.596	1.32	1.27
PTX-1	0.254	1.999	0.367	0.534	1.18	1.14
PTX-2	0.254	1.999	0.373	0.546	1.21	1.17
TNT	0.254	2.000	0.355	0.751	1.66	1.61
Pressed explosives †						
BTNEN/Wax (90/10)	0.251	2.009	0.379	0.427	0.95	0.92
BTNEU/Wax (90/10)	0.251	2.012	0.367	0.507	1.13	1.10
Comp A-3	0.252	2.012	0.367	0.474	1.17	1.13
MOX-2B	0.248	2.008	0.461	1.289	2.91	2.79
Pentolite (50/50)	0.252	2.011	0.363	0.638	1.41	1.27
RDX-Wax (95/5)	0.253	2.010	0.370	0.509	1.13	1.09
RDX/Wax (85/15)	0.251	2.014	0.350	0.566	1.26	1.23
Tetryl	0.254	2.011	0.371	0.660	1.45	1.41
TNT	0.253	2.012	0.348	0.972	2.15	2.10

* Test specimens – cylinders of AISI 1045 cold-drawn, seamless-steel tubing; stress relief annealed; hardness approx. 100 Rockwell B

† Pressed Explosives – 2-in. diameter pellets; 1-in. high; pressed at pressure of 16,000 psi

2—6.2.3.1 (C) *Striking Velocity*

The striking velocity of a fragment v_s can be expressed by

$$v_s = v_o e^{-\frac{C_D \bar{A}_F \rho}{m} r} \qquad (2\text{—}10)$$

where

v_o = initial velocity of fragment, fps (see Eq. 2—11)

C_D = average drag coefficient of fragment (see Refs. 11, 12)

$\bar{A}_F$ = average presented area of fragment, sq in.

ρ = density of air, slug/ft^3

m = mass of fragment, grains

r = range from point of burst to target, ft

2—6.2.3.2 (C) *Initial Velocity*[13]

For cylinders, the initial velocity v_o of a fragment can be predicted by:

$$v_o = \sqrt{2E}\sqrt{\frac{C/W}{1 + 0.5\,(C/W)}} \qquad (2\text{—}11)$$

where

$\sqrt{2E}$ = a constant (Gurney constant) for each type of explosive, ft/sec

C = weight of explosive, grains

W = weight of fragmenting metal, grains

Eq. 2—11 may be used to calculate v_o for spheres by changing $0.5(C/W)$ in the denominator to $0.6(C/W)$.

Table 2—2 lists values of $\sqrt{2E}$ for commonly used explosives. For further data on these explosives, see par. 2—10.

Figs. 2—2 and 2—3 may be used to determine the value of v_o when the outside diameter d_o and thickness t of the casing, the ratio of explosive density to casing density ρ_c/ρ_m, and $\sqrt{2E}$ are known. The procedure for determining v_o is as follows:

TABLE 2-2(C). VALUES OF GURNEY CONSTANT $\sqrt{2E}$ FOR COMMONLY USED EXPLOSIVES

Explosive	$\sqrt{2E}$ (ft/sec)
HMX	9500 *
RDX	9200
Octol	9200
Composition B	8800
TNT	8000

* ESTIMATED

(1) Knowing the value of t/d_o, determine the value of $\frac{C/W}{\rho_c/\rho_m}$ from Fig. 2—2.

(2) Multiply ρ_c/ρ_m by this value to obtain C/W.

(3) Knowing the value of C/W, determine $v_o/\sqrt{2E}$ from Fig. 2—3.

(4) Multiply $\sqrt{2E}$ by this value to obtain v_o.

2—7 (C) DESIGN APPROACH

2—7.1 (C) GENERAL

A hand grenade designer will be faced with one of two different design problems: (1) he may be required to design a completely new grenade to conform with a list of requirements prepared by the Army; or (2) he may be required to redesign an existing grenade to improve its performance. Obviously, the solution to the second problem is simpler than that to the first. Much actual test data on lethality, fragmentation patterns, fragmentation velocity, etc., will be available for the existing grenade. Therefore, the effects of design changes on these parameters are usually relatively easy to predict. On the other hand, when designing a new grenade, the designer does not have these data available and, therefore, he must compute such grenade parameters as lethality, fragmentation pattern, and fragmentation

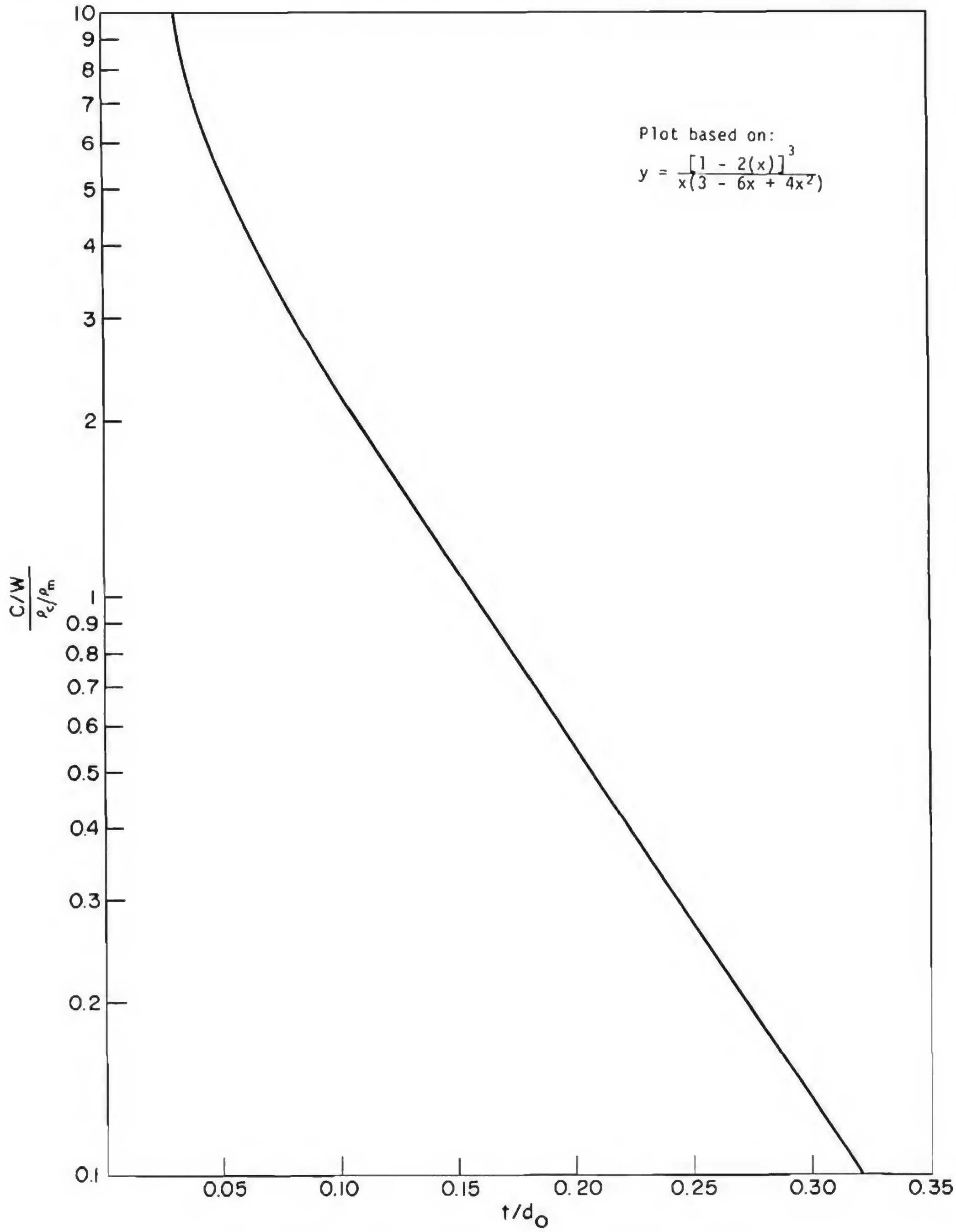

FIGURE 2—2(U)—GRAPH FOR DETERMINING C/W[4]

velocity analytically using the design formulas given in the preceding paragraphs.

Because of the interrelationships among the various design parameters, there is no strict procedure for designing a new grenade. Calculations can be started for any one parameter, and the data derived can be used to continue the calculations. In any event, before the calculations are started, a preliminary physical design of the grenade should be sketched within the specified size and weight limits, and certain values must be chosen as a start. These values, of course, should be related to some typical documented data derived from experience. Then, the mathematical

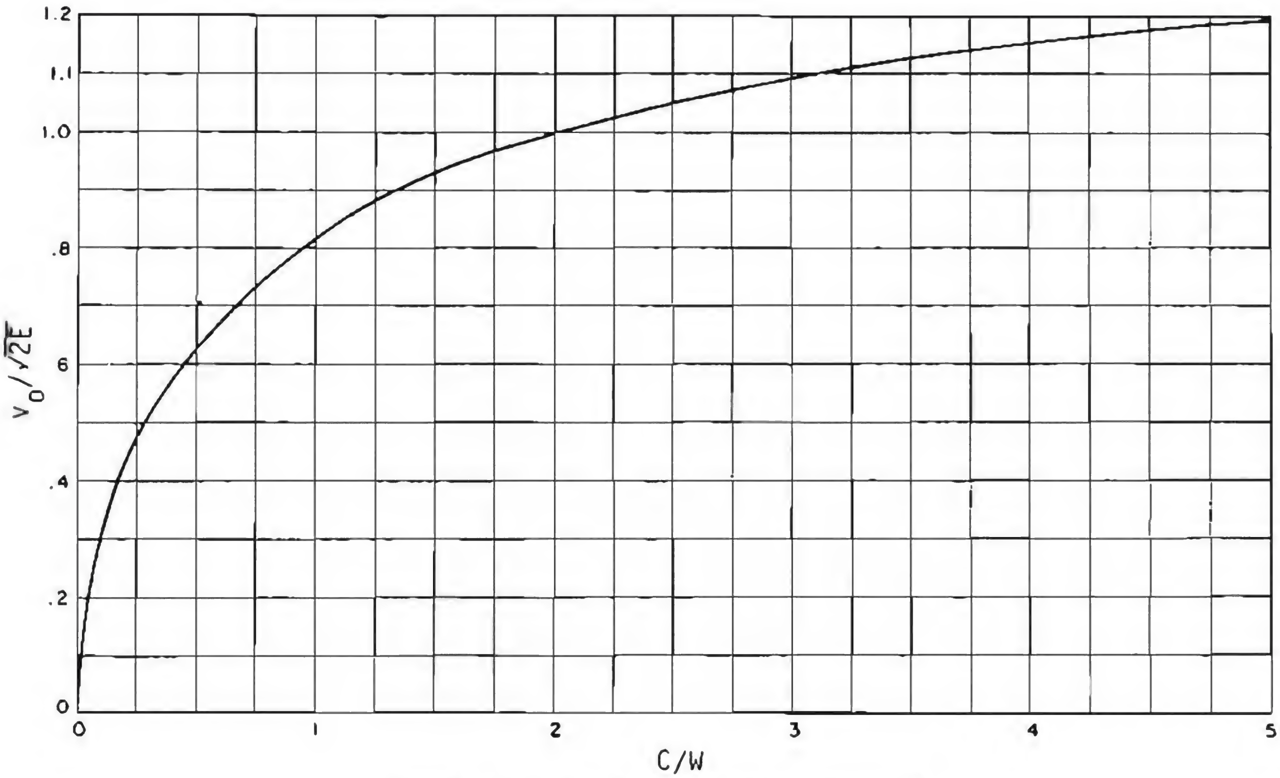

FIGURE 2—3(U)—GRAPH FOR DETERMINING V_0 [4]

calculations can be made to complete the design. However, since the calculations are based on some empirically chosen values, the final design must be proved out mathematically to see that various parameters are compatible, and that the desired characteristics are attained. This often results in certain modifications being made so that the mathematical calculations must be repeated. Sometimes, this must be done a number of times before the design-on-paper appears feasible.

Experimental models should then be made to test the actual performance of the grenade. The equations can then be used to analyze the performance test data, and to improve the grenade until a reliable design is attained.

It can be seen from the above that a considerable amount of empirical design is required in grenade development because of the interrelated characteristics of the grenade elements. Because of this, a knowledge is needed of the characteristics of all of the elements that comprise a grenade before a preliminary design is attempted; this will minimize the number of modifications that will be required during the calculations. This information is given later in this chapter. A typical approach to the design of a new fragmentation grenade is covered in the paragraphs which follow.

2—7.2(U) DESIGN PROCEDURE

Initial action in design procedure should be a system analysis by the weapon system analyst with a view toward establishing design parameters consistent with military requirements. The weapon system analyst, using high speed computer techniques and considering various concepts, will make parametric studies to evaluate unit effectiveness, thrower safety, tradeoffs, cost effectiveness, etc., to determine optimum parameters such as fragment size, fragment weight, number of fragments, grenade weight, grenade configuration, etc. The specific procedure for this analysis is exceedingly complex and beyond the scope of this handbook.

2—8 (U) PHYSICAL DESIGN FACTORS

2—8.1 (U) SIZE

The physical size of a hand grenade affects both the distance that the grenade can be thrown and the accuracy with which it can be thrown. To an extent, the size of a grenade is affected by the required fragmentation characteristics. For a given-size preformed fragment (par. 2—8.4), a larger grenade can produce more fragments than a smaller one. Similarly, the C/W ratio of a grenade (par. 2—6.2.3.2) could be increased by making the grenade larger so that it could hold a greater quantity of explosive. However, the size of a hand grenade must be such that it can be comfortably gripped and easily thrown. Based on past experience, special grenades having a diameter in the range of 3 to 3-1/2 in., and barrel-shaped grenades having a diameter of about 2-1/2 to 3 in. and a length of about 4 to 5 in., meet these requirements. Because of the relatively small lethal area required for a fragmentation grenade as compared to other types of fragmenting projectiles, the required fragmentation pattern can be obtained within the size limitations given above.

2—8.2 (U) WEIGHT

The weight of a hand grenade determines, to a great extent, the distance that the grenade can be thrown and the accuracy with which it can be thrown (par. 2—5.3). Table 2—3 shows the accuracy with which various weight grenades can be thrown from standing, prone, and kneeling positions. The data are based on tests conducted with 22 trained soldiers who used whatever throwing style they felt was most convenient and most accurate. Throws were made with and without gloves, and test results indicate that the gloves had essentially no effect on the throwing accuracy. Table 2—3 indicates that accuracy decreases as the weight of a grenade increases, although the decrease in accuracy does not appear significant for grenades thrown from 20 yd.

2—8.3 (U) SHAPE [15]

The shape of a grenade has little effect on the distance that the grenade can be thrown. However, grenade shape is one of the primary factors controlling the projected pattern of the fragments.

The three basic shapes usually considered for hand grenades are shown in Fig. 2—4. From the theoretical patterns shown, it can be seen that the spherical grenade produces the most uniform coverage. The barrel-shaped grenade produces nearly uniform coverage, but has some voids. The cylindrically shaped grenade produces a relatively nonuniform coverage; therefore, this shape is generally not considered for fragmentation grenades. It would be considered only if lowest possible unit cost was the overriding design requirement. The body of a cylindrically shaped grenade can be made essentially as a tin can, with notched sheet steel wrapped around its inside to produce fragments. The Soviet Model RG-42 fragmentation hand grenade is designed this way, making it much cheaper to produce than the U. S. M26 fragmentation hand grenade[5]. However, tests indicate that the lethal area of the U. S. M26 grenade is 1-1/2 to 3-1/2 times that of the Soviet RG-42 grenade.

To a certain extent, it is possible to choose the angle over which fragments are projected independently of other initial fragment parameters. Thus, the total unfuzed weight W of the grenade, the explosive charge-to-weight ratio C/W, the weight of each fragment, and the initial fragment velocity may be specified, and any direction of projection of the fragments in space can be realized. For example, for the barrel-shaped grenade shown in Fig. 2—4, the angle θ, which determines the range of directions from θ to $(\pi - \theta)$ over which fragments are projected, may be arbitrarily chosen. Then, the casing radius R, diameter D, and length L can be set to obtain the desired value of C. Since W increases continuously with wall thickness T, the value of T can be set to give the desired value of W and, consequently, the desired values of C/W and initial fragment velocity.

TABLE 2-3(U). PROBABILITY OF GRENADE IMPACT WITHIN X FEET OF TARGET [15]

x, ft	Weight of Grenade			
	12 oz [1]	15 oz [2]	18 oz [1]	22 oz [1]
	Thrown from 20 yd, prone			
0	0	0	0	0
2.5	.10	.10	.09	.02
5.0	.32	.28	.23	.17
7.5	.55	.48	.40	.55
10.0	.77	.68	.60	.72
12.5	.88	.82	.76	.81
15.0	.94	.90	.87	.89
17.5	.97	.95	.93	.94
20.0	.99	.97	.95	.97
	Thrown from 30 yd, kneeling			
0	0	0	0	0
2.5	.13	.11	.09	.07
5.0	.34	.30	.26	.18
7.5	.58	.52	.45	.36
10.0	.76	.68	.61	.51
12.5	.86	.80	.73	.63
15.0	.93	.86	.80	.75
17.5	.95	.90	.86	.85
20.0	.96	.93	.90	.90
	Thrown from 40 yd, standing			
0	0	0	0	0
2.5	.06	.06	.06	.04
5.0	.18	.16	.13	.12
7.5	.32	.28	.23	.22
10.0	.47	.41	.35	.32
12.5	.58	.52	.47	.42
15.0	.70	.64	.58	.51
17.5	.82	.74	.67	.59
20.0	.90	.82	.75	.66

[1] Observed values

[2] Interpolated between 12 and 18 oz

Although the desired θ was chosen initially, certain practical limitations make θ only approximately attainable. While the values of L and D were set to produce the desired θ, L and D also affect other grenade parameters in the following ways: (1) the maximum dimension of a fragment depends on D, (2) the initial velocity of a fragment depends, to a slight extent, on the shape of the grenade, and (3) low values of length-to-diameter ratios L/D may accentuate end-effect (par. 2—8.4.3.4),

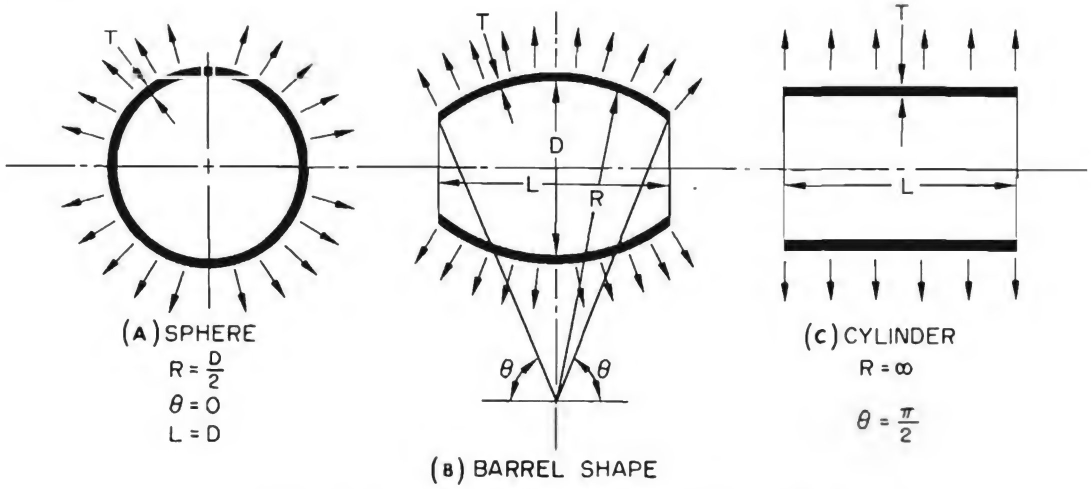

FIGURE 2—4(U)—POSSIBLE SHAPES FOR HAND GRENADES[15]

which is undesirable. Furthermore, the maximum diameter and maximum length of the grenade will probably be restricted by the design specification.

To determine the optimum shape of a hand grenade casing, consider a set of grenades of equal total weight, and equal C/W ratio. Thus, the explosive weight and the casing weight are fixed, and, to a first approximation, so is the initial fragment velocity. Assume that each grenade employs controlled fragmentation (par. 2—8.4) and that the number of fragments and the fragment mass are the same for each grenade. Under these conditions and assumptions, then, only the range of directions over which the fragments are projected will be permitted to vary, while the other initial conditions remain fixed.

From Eqs. 2—2 and 2—3, the probability $P_{hk}(r)$ of obtaining 5-second incapacitation at distance r can be expressed as

$$P_{hk}(r) = \frac{\Omega}{4\pi}\left(1 - e^{-\frac{K}{\Omega}}\right) \tag{2—12}$$

where

Ω = solid angle throughout which fragments are projected

K = a constant = $\dfrac{A_T N_m P_{hk}}{r^2}$

A_T = target area exposed to burst, sq ft

N_m = total number of fragments of given mass

r = distance from point of burst to target, ft

P_{hk} = probability of incapacitation

In this case, the quantity K/Ω is the expected number of incapacitating fragments that will strike the target. Now, assume further that each grenade in the set under consideration is used in the same tactical situation so that A_T and r are fixed, and K is a constant. Based on these and the previous assumptions, $P_{hk}(r)$ will depend

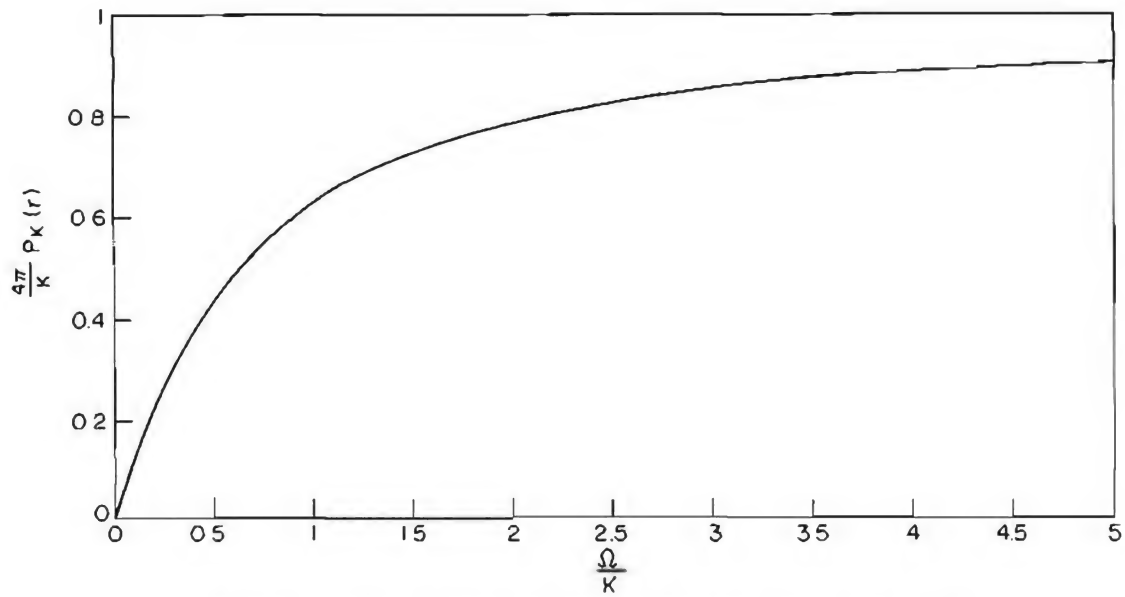

FIGURE 2—5(U)—EFFECT OF SHAPE ON GRENADE EFFECTIVENESS [15]

only on Ω. Eq. 2—12 is illustrated in Fig. 2—5 which shows that the probability $P_{hk}(r)$ of obtaining 5-second incapacitation multiplied by the constant $\frac{4\pi}{\kappa}$ increases with the solid angle over which the fragments are projected. Therefore, a higher average effectiveness is obtained by spreading the fragments in space rather than by confining them and relying on the chance of the target being caught in the spray. The curve in Figure 2—5 indicates that the optimum shape for a fragmentation hand grenade is spherical. The slope indicates that when κ is large, so that Ω / κ is small, any increase in Ω is very advantageous. On the other hand, when κ is small, so that Ω / κ is large, a small change in Ω is not too important.

2—8.4(U) CONTROLLED FRAGMENTATION

Controlled fragmentation provides a means for controlling the number, size, shape, and velocity of grenade fragments. Three basic methods for controlling hand grenade fragmentation are: (1) rotated casings, (2) notched wire, and (3) notched ring. Each type is described in the paragraphs which follow.

2—8.4.1 (U) Notched Casing

Older-type fragmentation grenades used a cast-iron notched casing to provide fragmentation control (Fig. 2—6). This technique is only partially effective because the casing will not reliably break up at the grooves. Furthermore, it is difficult to manufacture a casing of this type that is capable of breaking up into a large number of small, high velocity fragments, which is a desirable characteristic of fragmentation grenades. Since this characteristic can be more easily produced using other controlled fragmentation methods, the notched casing method is not considered for present-day fragmentation grenades.

2—8.4.2 (U) Notched Wire or Notched Rings

A notched wire spirally wrapped around a liner, or notched rings fitted over a liner, provides a reliable method of controlling fragmentation (Fig. 2—7). Whether the notched wire or the notched rings are used, the liner must be of plastic or thin metal so that it contributes essentially no fragments. It should be as thin as possible, consistent with manufacturing and strength considerations. For laminated phenolic plastic tubing, a thickness of 5 percent of its radius has proven satisfactory[4].

FIGURE 2—6(U)—NOTCHED CASING FOR CONTROLLED FRAGMENTATION

When selecting the material for fragmentation, the ability of the material to withstand the force of detonation must be considered. For example, at first glance, glass might appear to be a good material because of the sharp pieces into which it can be broken. However, glass tends to pulverize when exposed to the forces of normally acceptable grenade explosives.

At present, steel appears to be the best material for fragmentation. Metals of higher densities than steel are more difficult to form into fragments of the desired mass and shape. Furthermore, for a given weight of explosive, fragments made from these metals cannot be projected as far as steel fragments. Fragments made from metals with lower densities than steel are generally unsatisfactory because of their relatively low kinetic energy. The steel used to manufacture the notched wire or ring should have a tensile strength of 100,000 to 120,000 psi and should be free from surface cracks and inclusions.

In fragmentation grenade design, notched wire is preferred over notched rings. A fragmentation grenade would require rings that are too thin for economical manufacture. Furthermore, it is easier to manufacture the grenade with notched wire than with notched rings.

The dimensions of the wire and the distance between notches are determined by the number of fragments required and the desired fragment characteristics. Wire dimensions for the M26 fragmentation hand grenade, which is the present-day standard U. S. fragmentation grenade, are shown in Fig. 2—8.

FIGURE 2—7(U)—GROOVED WIRE AND GROOVED RINGS FOR CONTROLLED FRAGMENTATION [24]

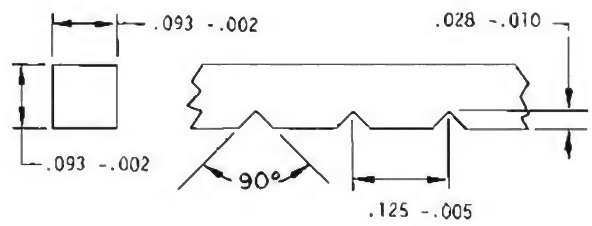

FIGURE 2—8(U)—NOTCHED WIRE FOR THE M26 FRAGMENTATION HAND GRENADE[5]

2—8.4.3 (U) Fragmentation Losses[15]

To compute the probability of incapacitation for any type of fragmentation grenade, various fragmentation losses must be considered. These losses reduce the actual effectiveness of the grenade to a level less than its theoretical "optimum" effectiveness. Optimum effectiveness means the effectiveness that could be obtained if the grenade had no fuze, if the casing were perfectly packed with fragments, and if the projected fragments retained their original mass and shape. The losses that result from each of these factors are discussed in the paragraphs which follow.

2—8.4.3.1 (U) Fuze Volume

A fuze occupies space that could otherwise be occupied by explosives or fragments. A typical fragmentation hand grenade fuze has a volume of 1.5 to 2.0 in. This volume must be deducted from the maximum explosive volume to allow for the presence of the fuze. The initial fragment velocity, therefore, must also be reduced because of the reduction in explosive volume.

Another deduction must be made for the fragments displaced by the fuze. On the assumption that the fuze contributes no effective fragments, the void in the fragment spray is 5 to 15 percent, depending upon the particular type of casing and fuze.

2—8.4.3.2 (U) Packing Losses

The actual number of fragments obtained from a notched wire wrapping (par. 2—8.4.2) will be less than the optimum theoretical number. The loss in fragments is caused by imperfect packing or wrapping. Typically, a reduction of 10 percent in the theoretical number of fragments should be made to account for these losses.

2—8.4.3.3 (U) Breaking and Chipping of Fragments

No matter what method is used to control fragment mass, some fragments will break when the grenade detonates. This breakage reduces the number of incapacitating fragments projected by the grenade. To allow for this breakage, the theoretical number of incapacitating fragments should be reduced by about 10 to 15 percent to determine the actual number of incapacitating fragments.

The corners and edges of some of the projected incapacitating fragments will chip when the grenade detonates. Chipping reduces the weight of a projected fragment to a value below the value before projection, thereby slightly reducing the probability of incapacitation. However, this weight loss for rectangular parallelepiped steel fragments is of the order of 5 to 10 percent, and can usually be ignored.

2—8.4.3.4 (U) Closing Cap Losses

On barrel-shaped and spherical fragmentation grenades, the end opposite the fuze has a hole through which the explosive charge is cast. To prevent a blind spot in the fragment spray for this end of the grenade, the closing cap should be designed so that it projects fragments when the grenade bursts. The cap should be made from a tough steel, and notched on the inside surface (explosive side). The notches should be spaced so that the fragments projected by the cap are of the same weight as those projected from the grenade casing.

2—8.5 (U) EFFECTIVENESS OF VARIOUS GRENADE DESIGNS[15]

The paragraphs which follow compare the relative effectiveness of various theoretical grenade designs. The probability of incapacitation quoted are based on older wound ballistic data, which have been superseded by more precise data (see par. 2—6.1.1). While the individual values of

P_k are not precise, they permit a comparison of the effectiveness of different size grenades employing various values of charge-to-weight ratio C/W, and fragment weights.

2—8.5.1 (U) Overall Probability of Incapacitation

The probability that a hand grenade will incapacitate a point target depends upon the probability of incapacitation at a certain burst distance from the target and the probability of achieving that burst distance. If $P_k(r)$ is the probability of 5-sec incapacitation at burst distance r, and if $P(r)$ is the probability that a thrown grenade will burst within distance r of the target, then the probability P_k that a thrown hand grenade will incapacitate a point target within 5 sec is:

$$P_k = \int_0^{\infty} P_k(r) \frac{d\,P(r)}{dr}\,dr \qquad (2\text{—}13)$$

Values of r greater than 15 ft do not contribute appreciably to the integral for the following reasons: (1) $P_k(r)$ is nearly zero at 15 ft or more; (2) the vast majority of bursts are within 15 ft, so that at 15 ft $P(r)$ is nearly at its maximum and limiting value of unity.

2—8.5.2 (U) Spherical Versus Barrel-shaped Grenades

Barrel-shaped grenades, particularly the wire-wrapped type, are generally easier to make than a spherical grenade. However, a barrel-shaped grenade has the disadvantage of leaving voids in the fragmentation pattern.

The difference in $P_k(r)$ between a barrel-shaped grenade for which θ equals about 45° or less and a spherical grenade of equal weight C/W and fragment weight is greater for heavier grenades and for shorter burst distances. However, this is not true for very short burst distances, such as those up to a few feet, because at these distances the shape of the grenade has essentially no effect on $P_k(r)$. For example, at zero burst distance, $P_k(r)$ would equal 1 for any shape grenade. For this discussion, then, only burst distances of 5 ft or more are considered.

The higher the value of $P_k(r)$ for a spherical grenade, the greater will be the loss in $P_k(r)$ by changing to a barrel-shaped grenade. This is so because the slope of the $P_k(r)$ curve in Figure 2—5 is greatest for low values of Ω / K and, consequently, for large values of K. Now, assume that this grenade is changed to the barrel shape shown in Fig. 2—9 and that there is no contribution of fragments from the fuze end or the end opposite the fuze. Then,

$$\frac{\Omega}{K} = \frac{.707 \times 4\pi}{20} = 0.444,$$

and the value of $\frac{4\pi}{K} P_k(r)$ will be 0.40.

Therefore, the change from a spherical to a barrel-shaped grenade has resulted in a 20 percent reduction in $P_k(r)$ at the 5-ft burst position.

Evaluating the above results in a more practical sense, however, indicates that the difference in $P_k(r)$ will be less than 20 percent. This is because a spherical grenade must also employ a fuze and because fragments projected from the end opposite the

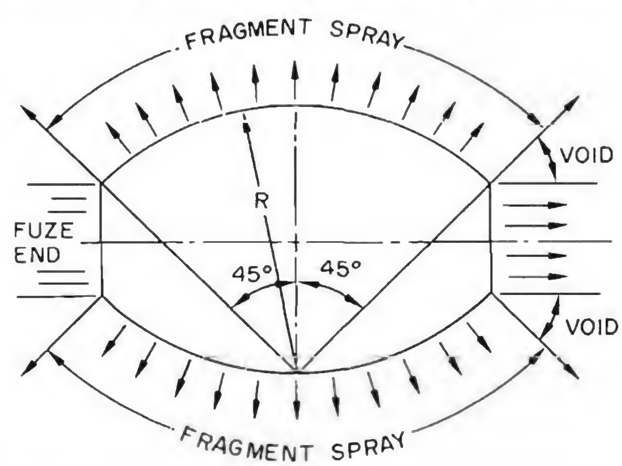

FIGURE 2—9(U)—APPROXIMATE FRAGMENTATION PATTERN FOR A BARREL-SHAPED GRENADE[15]

fuze (par. 2—8.4.4.4) will contribute to the $P_k(r)$ of the barrel-shaped grenade. For the 18-oz (fuzed) spherical grenade, it is estimated that a change to barrel shape will result in about an 8 percent reduction in $P_k(r)$ at 5 ft; for the 15-oz and 9-oz grenades, the estimated reduction is about 4 percent and 2 percent, respectively. At the 10- and 15-ft burst positions, the reductions are considerably less. The barrel-shaped grenade, then, may be considered slightly less effective than the spherical grenade at the 5-ft burst distances, and about as effective at the 10- and 15-ft burst distances.

2—9 (U) FUZING

Generally, three basic types of fuzing have been considered for fragmentation grenades: (1) proximity fuzing, (2) pyrotechnic time delay fuzing, and (3) impact fuzing. Each is discussed in the paragraphs which follow.

2—9.1 (U) PROXIMITY FUZING

The most effective fragmentation hand grenade is one that detonates above the ground and projects its fragments in all directions below the horizontal. A grenade of this type requires some type of proximity fuze to sense the proper burst height and detonate the grenade at that height. Furthermore, a suitable grenade configuration and some method of orienting the grenade in a particular direction at the time of burst are required. Both of these requirements increase the cost, weight, and complexity of the grenade. These factors offset the greater effectiveness of proximity fuzing when compared to other grenade fuzing methods. Therefore, a proximity fuze has never been used in any past or present-day fragmentation hand grenades, and there is little, if any, current effort to develop one.

2—9.2 (U) PYROTECHNIC TIME DELAY FUZING

The pyrotechnic time delay fuze (Fig. 2—10) is, by far, the type used most often for fragmentation hand grenades. This type of fuze employs a delay column of slow-burning powder that is ignited when the grenade is released by the thrower. The column requires a fixed time to burn through, which is typically about 4.5 to 5 sec, and at the expiration of this delay time it fires the detonator.

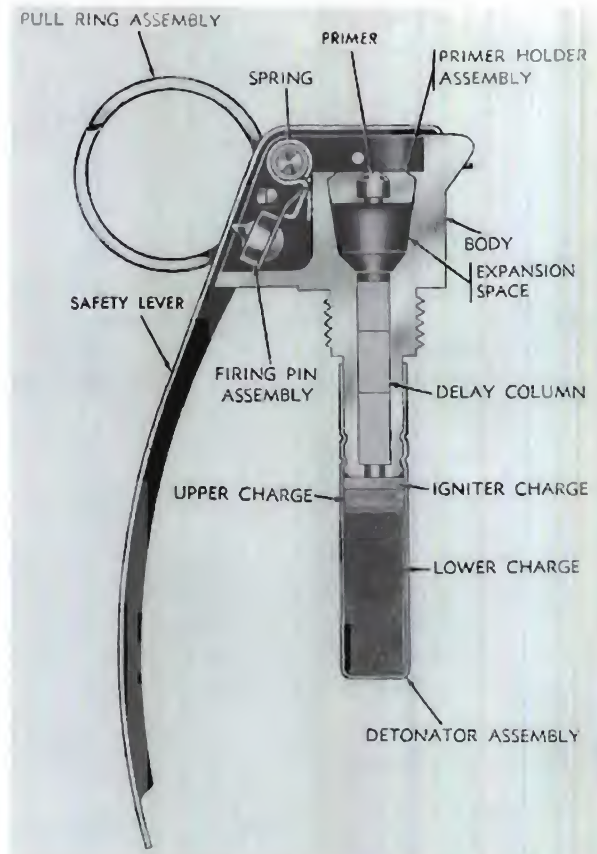

FIGURE 2—10(U)—TYPICAL PYROTECHNIC TIME DELAY FUZE

Fragmentation grenades employing pyrotechnic time delay fuzes have proven acceptable to the military, and their cost is low compared to the cost of grenades employing other fuzing techniques. However, grenades of this type have a number of tactical limitations due to the time delay element, the most important of which are: (1) an enemy might be able to take cover before the grenade detonates, (2) the grenade might roll back downhill and detonate near friendly personnel, and (3) the grenade might be picked up and thrown back by an enemy.

Mechanical, electrical, and chemical devices might be incorporated into a grenade fuze to provide the required time delay. However, these devices all possess the same tactical disadvantages listed above and, in addition, are more expensive to produce than the pyrotechnic time delay fuze.

Although present-day fragmentation hand grenades employ pyrotechnic time delay fuzes almost exclusively, there are many military applications in which impact fuzing techniques are desirable (par. 2—9.3).

Broadly, the pyrotechnic time delay fuze consists of an explosive train, safety and arming devices, and a striker assembly. The explosive train is discussed in par. 2—10. Actually, the fuze does not contain the complete explosive train; the main charge is contained in the grenade casing.

2—9.2.1 (U) Safety and Arming

Ideally, an ammunition item should arm only when it experiences forces unique to the launch environment. At all other times — i. e., during storage, transportation, and handling — the fuze should remain safe (unarmed). Most ammunition items do experience unique forces at the time of launch. For example, a projectile experiences a very high setback force when it is fired from a gun. It may also experience a very high rate of spin. The forces resulting from both setback and spin can be used to cause the fuze to arm. Similarly, missiles and rockets experience high acceleration forces after they are launched, which may be used to cause the fuze to arm.

Unfortunately, a hand grenade does not experience any unique forces at the time it is thrown, or launched, or while it is in flight. Therefore, arming must occur as a result of some action or event prior to the time the grenade is thrown.

Certain other problems arise in the design of safety and arming devices for hand grenades. A mandatory requirement for fuzes is that they must be "detonator safe." Detonator safe means that if the detonator functions accidentally, it cannot initiate the next explosive train component. This can be accomplished by using an out-of-line detonator that rotates into place when the fuze undergoes a high setback force. Or, an interrupter, which forms a physical barrier between the detonator and the next explosive train component, can be moved out of the way when the fuze undergoes setback or some other force associated with launch or flight.

Since hand grenades experience no unique forces that can be used to perform the functions described above, the detonator safe requirement has been waived for past and present-day hand grenade fuzes.

Actually, hand grenades can be designed so that they are detonator safe. An out-of-line detonator can be moved into place or an interrupter moved out of the way by the thrower just prior to throwing the grenade. Or, a small electric motor can be used to accomplish either of these functions after the grenade is thrown. These approaches are difficult, however, because of the size and weight limitations imposed on hand grenades.

While the detonator safe requirement has been waived for existing hand grenades, it is desirable that a practical detonator safe device be incorporated into future fuze designs. Some type of device requiring both automatic and manual operation during the arming-throwing cycle is preferred, provided the device is practical, inexpensive, and does not detract from the tactical use or effectiveness of a hand grenade.

Since there are no unique forces associated with the launch or flight of a hand grenade that may be used for arming, arming must occur as the result of some action or event prior to the time the grenade is thrown. To date, the best method of accomplishing this is to have the thrower perform some positive action that will cause the fuze to arm. In Fig. 2—10, the firing pin is restrained by the safety lever. The safety lever, in turn, is restrained at one end by the pull ring assembly, which is simply a cotter pin attached to a metal ring, and

by a T-lug at the other end (Fig. 2—11). The fuze becomes armed when the thrower, while holding the lever in place, pulls the safety pin out of the fuze body. Only the pressure of the thrower's hand holding the safety lever on the fuze prevents the fuze from functioning. When the grenade is thrown, the lever is released and is forced out and away from the grenade body by the striker. The striker continues moving in an arc and hits the primer, thereby initiating the fuze.

The use of a lever and a pull ring assembly to provide safety is typical of almost all U. S. and foreign hand grenades. However, at least one foreign grenade uses a third device, a wire ring around the head of the fuze and the lever, to prevent the lever from moving [17]. While this device provides additional safety, removing the ring creates an additional operation that the thrower must perform before throwing the grenade.

Another major safety requirement for a hand grenade is that the probability of a premature function after the grenade is thrown must be ideally zero for all practical purposes. To ensure this low probability, the reliability of the delay column must be such that short burning times are very improbable. A reliable delay column, by itself, will not ensure a low probability of premature function. The reliability is also dependent upon the design and construction of other fuze components, and the design and construction of the fuze housing itself. For example, a combination of excessively porous fuze castings and cracked or leaky detonator cups in M26 fragmentation grenades was believed to have been the cause of a number of premature functions [18]. The primer output flash broke through the porous casting, bypassed the delay column, and initiated the cracked detonator (Fig. 2—12). Thus, grenade detonation occurred after essentially zero time delay.

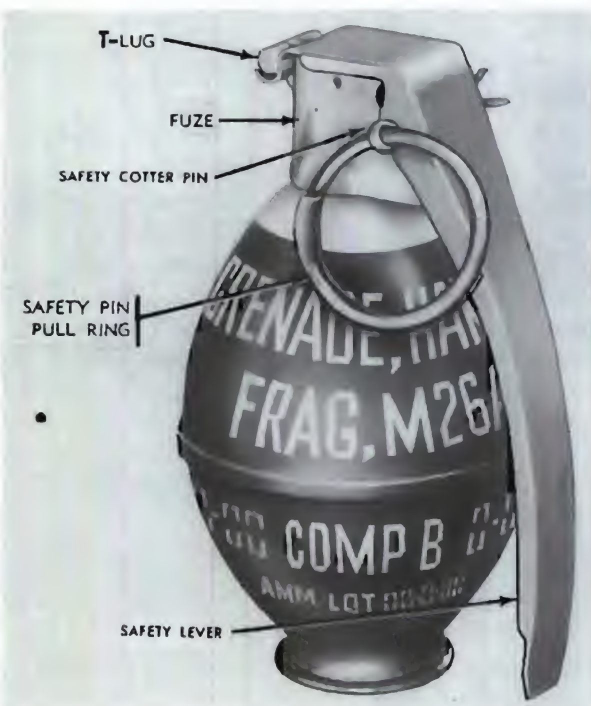

FIGURE 2—11(U)—SAFETY LEVER AND PULL RING ASSEMBLY

2—9.2.2(U) Striker Assembly [19]

The striker assembly used in almost all present-day hand grenades consists basically of a firing pin attached to a torsion-type wire coil spring (Fig. 2—10). When a grenade is assembled, the firing pin is cocked, which winds the spring. The spring force F is equal to

$$F = \frac{EI_A}{\ell r}\theta$$

where

E = Young's modulus of elasticity, psi

ℓ = length of spring, in.

r = lever arm of force F, in.

θ = angular displacement of coil, rad

I_A = second moment of cross-sectional area, in.^{4}, which can be expressed as

$$I_A = \frac{\pi d_w^4}{64}$$

where d_w = diameter of wire, in.

Typical spring dimensions might be: ℓ = 0.50 in.; r = 0.50 in.; d_w = 0.035 in.; $E = 30 \times 10^6$ psi; and $\theta = \pi$ rad. Therefore,

$$I_A = \frac{\pi(0.5)^4}{64} \approx 0.073 \times 10^{-6} \text{ in.}^4$$

and

$$F = \frac{(30 \times 10^6)(0.073 \times 10^{-6})}{(0.5)(0.5)} \pi = 28 \text{ lb}$$

Fragmentation hand grenades almost always use percussion-type primers (par. 2—10.2.1.1). The energy needed to initiate the percussion primer is obtained from the potential energy H_s stored in the spring and released when the striker swings. This potential energy can be expressed as:

$$H_s = G\theta = \int_0^{\pi} k\theta r d\theta$$

where

G = the torque that is proportional to deflection (= $k\theta$)

k = spring constant, lb/rad

r = radius arm of the striker that swings through π radians

Since r = 0.5 in. and $k = \frac{28}{\pi}$ lb/rad, then

$$H_s = 7\pi \text{ lb-in.} \approx 352 \text{ in.-oz}$$

If we assume that the striker assembly is only 50 percent efficient because of friction, the energy available as the striker hits the primer is 176 in.-oz.

Since obturated fuzes are preferred for fragmentation hand grenades (par. 2—10), the firing pin must not puncture or rupture the primer cup at the time of striker impact. Therefore, a blunt firing pin must be used. A typical firing pin radius is about 0.050 in. However, tests on flat firing pins and pins with a radius up to 0.023 in. indicate that the radius has little effect on firing pin sensitivity [20].

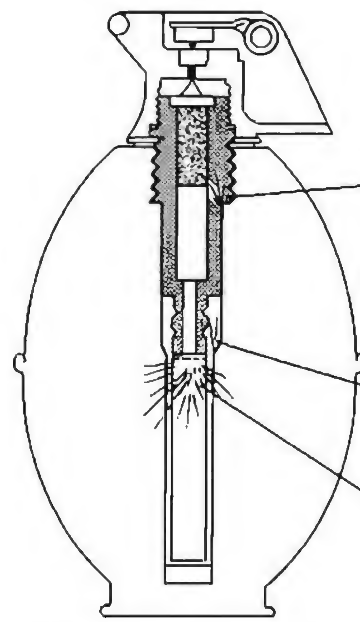

FIGURE 2—12(U)—ONE CAUSE OF PREMATURE FUNCTION IN HAND GRENADE [18]

2—9.3(U) IMPACT FUZING

The primary disadvantages of the pyrotechnic time delay fuze (par. 2—9.2) can be overcome by using an impact fuze. However, impact fuzes are more complex and more expensive, and, therefore, have not replaced pyrotechnic time delay fuzes for general use.

The only current U. S. fragmentation hand grenade fuze employing impact function is the M217 electric fuze which is designed for use with the M26 grenade. The M217 fuze includes both an impact function and an overriding time delay function. The time delay function in the M217 fuze, like that in the pyrotechnic time delay fuze, is produced by initiating incendiary material. However, in the M217, the delay function occurs due to heat transfer through solid thermal barriers; incendiary flash transfer does not occur.

The M217 fuze is shown in Fig. 2—13. It consists essentially of a power supply (thermal battery), an omnidirectional impact switch, an electric detonator, a fusible-link arming delay switch, and a fusible-link self-destruction switch. The arming sequence is as follows:

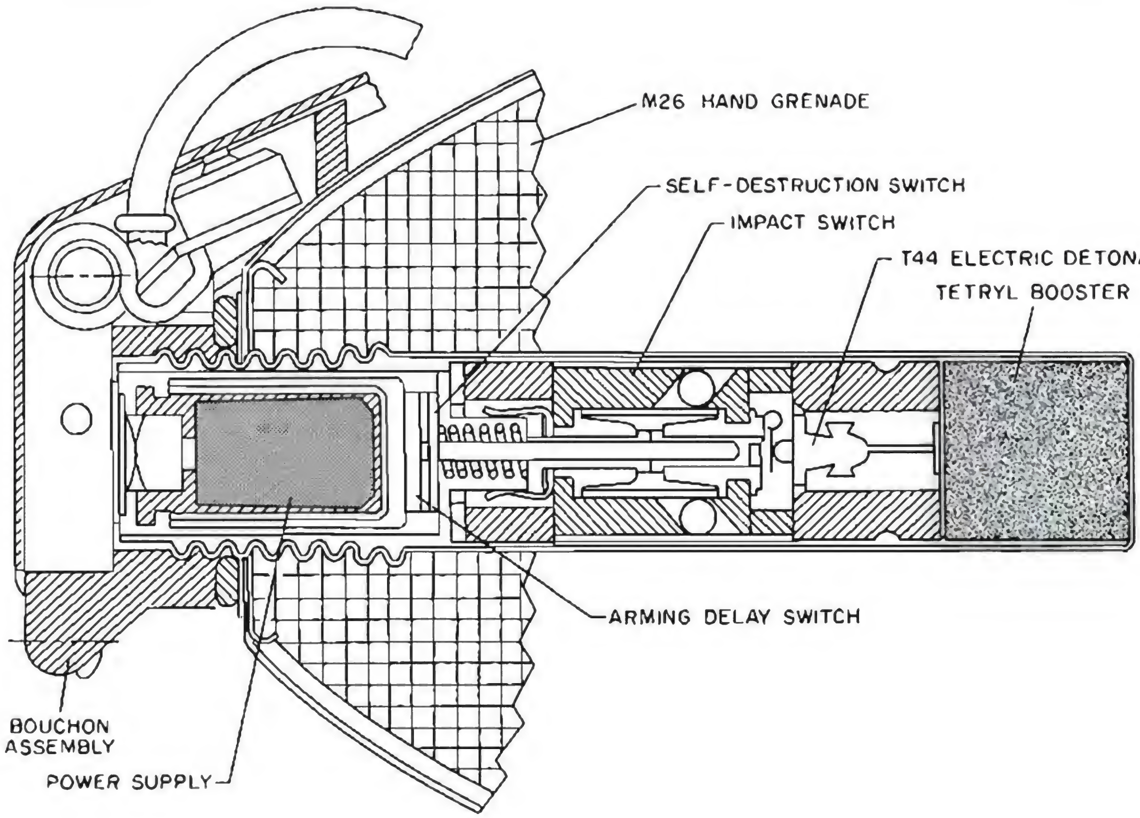

FIGURE 2—13(U)—M217 ELECTRIC FUZE [21]

(a) When the grenade is thrown, the striker assembly (par. 2—9.2.2) initiates the percussion primer.

(b) The percussion primer, in turn, ignites a fast-burning pyrotechnic mixture of metal and oxidizer which raises the temperature of the thermal power supply to its actuation point within about 0.5 sec.

(c) Heat generated by the power supply then actuates the thermal arming switch about 1.5 sec after the grenade is thrown. This completes the arming process.

After arming is completed, any impact of the grenade that is equivalent to the impact resulting from a 6-in. drop on a hard surface will close the impact switch and complete the circuit from the power supply to the electric detonator, thereby causing the grenade to function. If no impact occurs, or if the impact is too weak to close the impact switch, the self-destruction switch (Fig. 2—14), which bypasses the impact switch, closes after about 4.5 sec to complete the circuit from the power supply to the detonator. The self-destruction switch, like the arming switch, is thermally activated by the heat from the thermal power supply.

The purpose of the 1.5-sec arming delay is to assure that the grenade is a safe distance from the thrower (about 60 ft) before detonation can occur. This arming delay also prevents immediate impact function if the thrower accidentally drops the grenade after withdrawing the safety pin. A dropped grenade will strike the ground in about 0.5 sec, which is less than the arming delay time, so that impact function cannot occur. Since the self-destruction switch does not close for about 4.5 sec, the thrower will usually have time to take cover, or to pick up and throw the armed grenade. However, if a dropped grenade should roll and strike a hard object, impact function can occur at any time after the arming delay period and before self-destruction occurs.

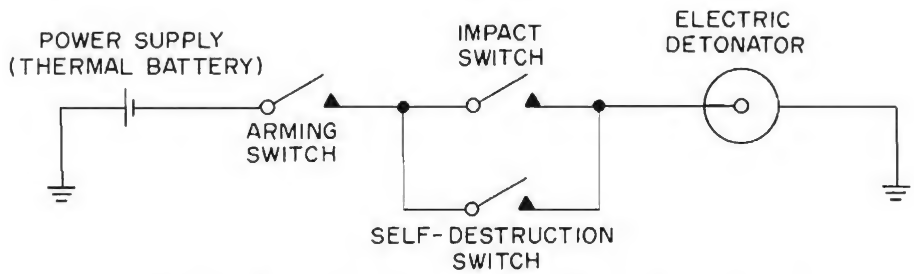

FIGURE 2—14(U)—ELECTRICAL CIRCUIT OF THE M217 FUZE[21]

2—9.3.1 (U) Impact Switches

Since the orientation of a hand grenade at the time of impact cannot be predicted, an omnidirectional impact switch must be used. Ideally, the sensitivity of the switch should be such that the grenade will detonate upon impact with even the very softest type of terrain, such as very soft snow. However, the maximum sensitivity of the switch is limited by the following factors: (1) the sensitivity must be low enough to permit the grenade to fly through light foliage without switch closure occurring, (2) the switch must not close should it become necessary to throw an armed grenade, and (3) the switch must not close when subjected to centrifugal forces developed by spinning the grenade about any axis when the grenade is thrown. Based on these factors, the M217 fuze uses an impact switch having a maximum sensitivity of 35 g. This provides sufficient sensitivity to cause impact function on almost any terrain, except very soft snow, following a flight of the grenade that is long enough to assure that the fuze has armed.

The M217 fuze uses a trembler switch of the type shown in Fig. 2—15 to provide impact capability. In its simplest form, a trembler switch is a mass-spring combination enclosed in a case. Upon impact with the ground, deceleration forces cause the mass to deflect the spring so that the spring makes contact with the case or other switch element to close an electrical circuit.

The switch shown in Fig. 2—15 uses steel balls (g-weights) which, upon deceleration of the grenade at impact, deflect leaf springs that serve as contacts. Eight mass-spring combinations in the switch are so arranged that no matter what the orientation of the grenade at impact, at least two or three of the balls will be accelerated toward the axis of the switch. The ball forces the end of the adjacent leaf spring through a small air gap so that the leaf spring contacts the center contact. Because of flexure of the spring after contact, the duration of closure is extended beyond the period of deceleration. This characteristic of switch operation is very important because it reduces contact chatter, and extends closure time for impacts of very short duration.

2—9.3.2 (U) Thermal Switches[23]

Thermal switches close (or open) electrical circuits when the switch reaches a certain temperature. Of the various types of thermal switches, the fusible-link type appears to be the most suitable for providing electrical time delays in grenades. Fusible-link thermal switches are small, rugged, reliable, and relatively inexpensive. There is little switch-to-switch variation in the temperature at which the switch closes. Furthermore, unlike many bimetallic-type thermal switches, fusible-link type thermal switches do not require individual calibration and adjustment.

Fig. 2—16 shows the fusible-link thermal switch used to provide the arming delay in the M217 impact fuze. It is activated by the heat from the thermal battery, and closes in about 1.5 sec after the thermal battery is initiated. A cadmium-lead-zinc alloy disk with a melting point of about 280°F and a perforated Fiberglas disk are sandwiched between the two switch contacts. When the alloy disk melts, molten

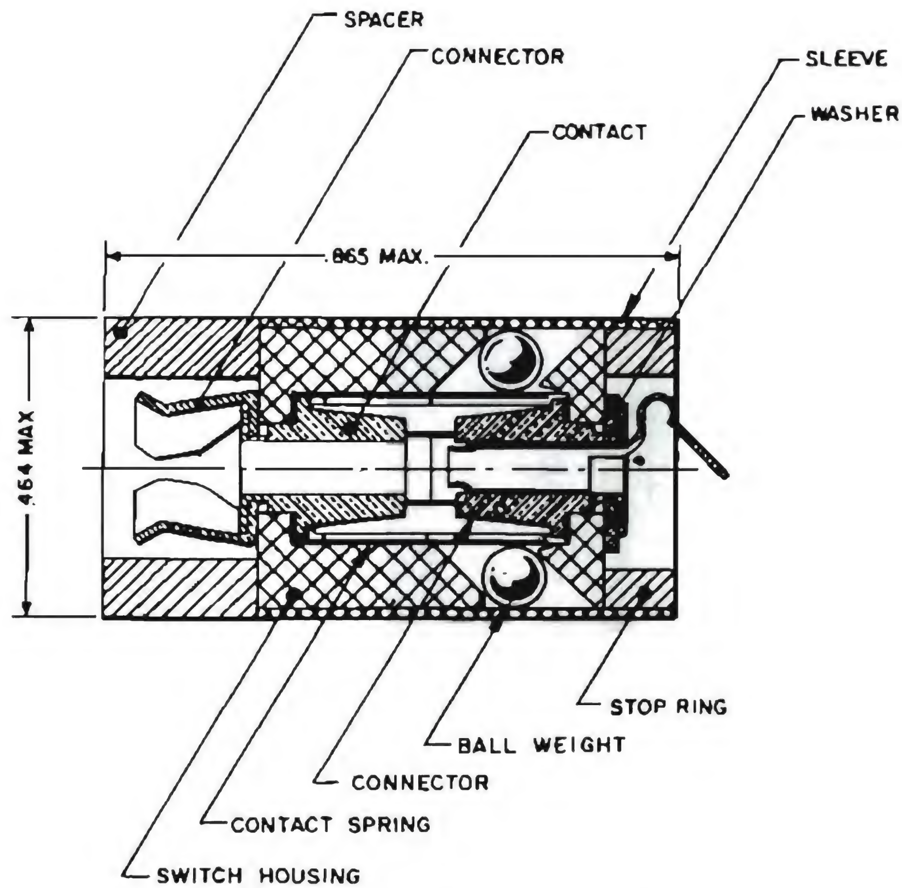

FIGURE 2—15(U)—TREMBLER-TYPE IMPACT SWITCH [22]

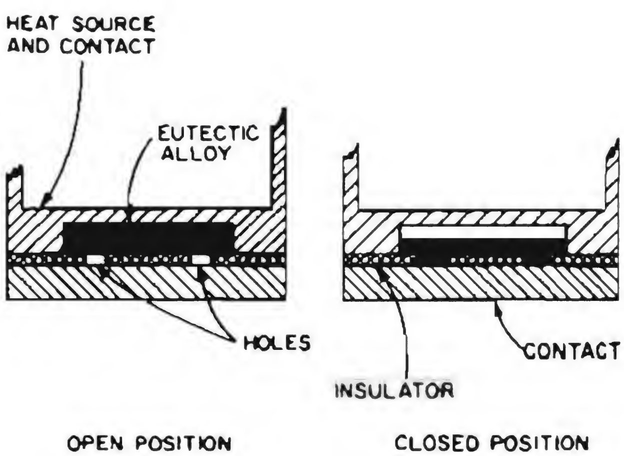

FIGURE 2—16(U)—FUSIBLE-LINK THERMAL SWITCH [23]

metal flows through the holes in the Fiberglas disk, thereby bridging the gap between the contacts and closing the switch.

More uniform and more reliable switch loading can be obtained by spring loading one of the switch contacts. The spring-loaded switch shown in Fig. 2—17 provides the 4.5-sec self-destruction delay for the M217 impact fuze. The thermally activated element of this switch is a pressed pellet of mercuric iodide which melts at about 500°F. When the pellet melts, the spring-loaded contact firmly presses against the other contact, thereby reducing the contact resistance of the closed switch to a few hundredths of an ohm.

2—9.3.3(U) Thermal Batteries

A thermal battery is basically a primary voltaic cell (or combination of cells) having a positive electrode, a negative electrode, a solid electrolyte, and a heat source. When the electrolyte is heated to about 275°F

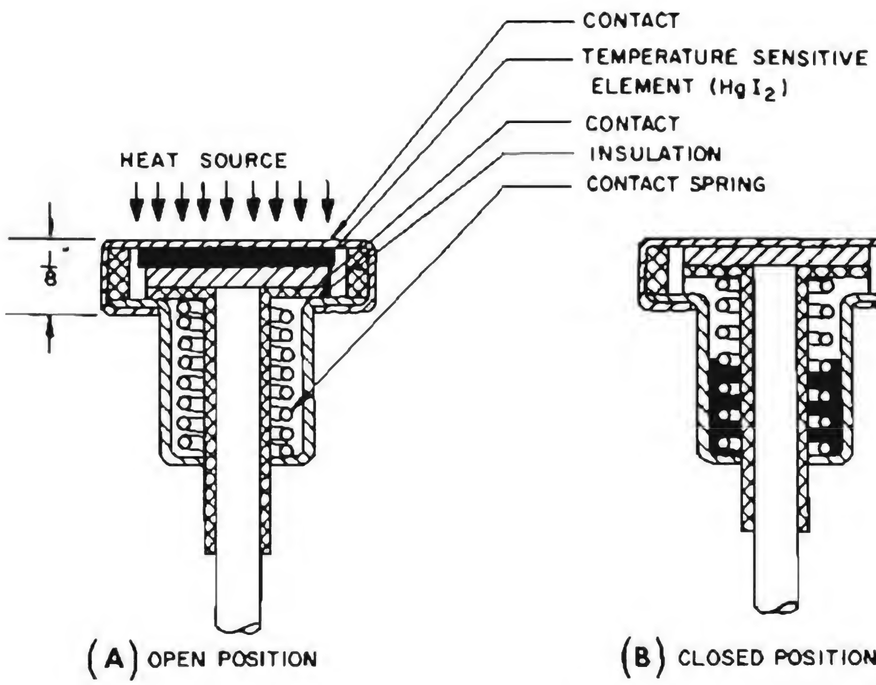

FIGURE 2—17(U)—SPRING-LOADED FUSIBLE-LINK THERMAL SWITCH[23]

or higher, it melts and becomes a liquid ionic conductor. The most common way to provide heat is to surround the cell (or cells) with a pyrotechnic material.

A thermal battery for hand grenades need only provide sufficient energy to fire an electric detonator. Therefore, a battery with a low output voltage and relatively low current, and having a short active life, can be used. For example, in the M217 fuze, the electric detonator is initiated by a single cell (1.5 volts) having an active life of about 15 to 20 sec. The battery is only about 0.5 in. long and 0.5 in. in diameter. It is simply, and reliably, initiated by a percussion primer.

Thermal batteries will perform satisfactorily over the temperature range normally specified for grenades, and can meet the shock and vibration requirements specified for grenades.

The minimum shelf life of a thermal battery is about 15 yr. Since the action of the heat source is irreversible, thermal batteries cannot be tested during storage, which is probably their main disadvantage.

2—9.3.4(U) Electric Detonators

The designer is referred to Reference 1 for a detailed discussion of various types of electrical detonators. However, the designer must keep in mind the need for proper shielding to prevent accidental initiation of the detonator by stray electromagnetic fields. For example, in the M217 fuze, all electrical components, including the electric detonator, are contained in a hermetically solder-sealed metal can. This can provides shielding against electromagnetic and electrostatic discharge, as well as protection against moisture.

2—10(U) EXPLOSIVE TRAINS

Explosive trains are covered in detail in Reference 1. The reader is referred to that reference for a detailed discussion of explosive train design techniques. Additional information is given in Reference 20 and References 24 through 28. The paragraphs which follow briefly discuss some of the important characteristics of explosive trains, explosives, and components.

An explosive train is an assembly of explosive elements arranged in order of decreasing sensitivity. Its purpose is to amplify a low-level impulse to a level high enough to detonate the main charge of a munition. A typical explosive train for a pyrotechnic delay (par. 2—9.2) fragmentation hand grenade consists of a primer, delay element, relay, detonator, and the main charge (Fig. 2—18). When the primer is struck by the grenade firing pin, it initiates, and, in turn, ignites the delay element. The delay element provides the time needed for the grenade to reach the target. The delay element, after burning through, fires the relay. (In most fragmentation grenade explosive trains, the relay is simply the last charge increment in the delay element.) The relay amplifies the relatively weak impulse from the delay element to a level high enough to fire the detonator which sets off the main charge.

2—10.1 (U) EXPLOSIVES

High explosives may be classified as primary high explosives and secondary high explosives. A primary high explosive is characterized by its extreme sensitivity to heat and shock. It is capable of building up from a deflagration to detonation in a short distance and time; it can also propagate a detonation wave in a very small diameter column. Typical materials classified as primary high explosives are lead azide, lead styphnate, and diazodinitrophenol (DDNP). Primary high explosives are normally used to detonate secondary high explosives.

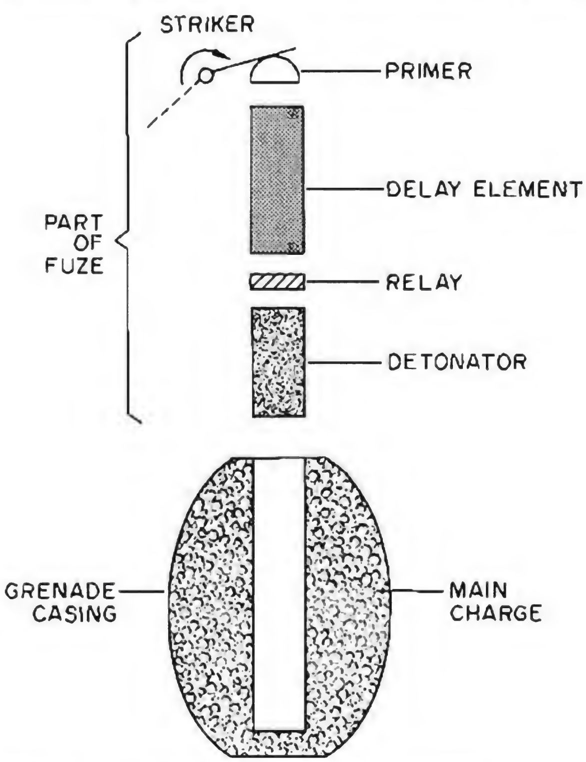

FIGURE 2—18(U)—ELEMENTS OF A TYPICAL FRAGMENTATION HAND GRENADE EXPLOSIVE TRAIN

A secondary high explosive is not readily initiated by heat and shock. Normally, a secondary high explosive must be initiated by a primary high explosive. Typical materials classified as secondary high explosives are PETN, RDX, and Composition B.

The most important characteristics of a high explosive are: (1) sensitivity, (2) stability, (3) brisance, (4) detonation rate, and (5) compatibility with other materials. Values of (1) through (4) for typical explosives now in use or being developed are given in Table 2—4. The compatibility of these explosives with various materials is given in Table 2—5. The compatibility of the explosives with metals, unless otherwise noted, represents the effect of the explosive in contact with the metals after being tested at ambient temperature for two years.

2—10.2 (U) EXPLOSIVE TRAIN COMPONENTS

Design considerations for explosive train components are discussed in detail in Reference 1. These considerations are reviewed briefly here with respect to fragmentation hand grenades.

2—10.2.1 (U) Primers

A primer is a relatively small, sensitive explosive component used as the first element of an explosive train. As such, it converts mechanical (or electrical) energy into explosive energy.

Primers may be classified according to the way they are initiated — i.e., percussion primers, stab primers, and electric

TABLE 2-4(C). CHARACTERISTICS OF MILITARY EXPLOSIVES[33]

NOTES

* - Tamped Crystalline TNT
D - Decomposes
I - Ignites
C - Crackles
E - Explodes
U - Unaffected
F - Flames erratically

Explosive	Chemical Name	Governing Specification	Composition, %	Sensitivity: Impact Test: Picatinny Test (Ht., In.)	Sensitivity: Impact Test: BuMines Test (Ht., Cm.)	Sensitivity: Pendulum Friction: Steel Shoe	Sensitivity: Pendulum Friction: Fiber Shoe	Sensitivity: Explosion Temperature (°C at 5 Seconds)	Sensitivity to Initiation by Tetryl Booster: Density (g/cc)	Sensitivity to Initiation by Tetryl Booster: 50% Gap (Inches)	Brisance (Grams of Sand Crushed)	Power: Ballistic Mortar TNT Equivalent	Power: Trauzl Test TNT Equivalent	Propagation of Detonation In Column 38 Inches Long (Minimum Diameter, In.)	Rate of Detonation (m/sec): Density, 1.60	Rate of Detonation (m/sec): Density, Normal	Density: Normal	Density: Crystal	Method of Loading	Blast Equivalent Weights (Bare Charge): Peak Overpressure TNT Equivalent	Blast Equivalent Weights (Bare Charge): Positive Impulse TNT Equivalent	Gurney Constant (ft/sec)
Composition B		MIL-C-401B	39 TNT, 60 RDX, 1 Wax	14	75	U	U	278 D	1.69	1.40	54.0	134	130	⅜	7840	7800	1.65		Cast	1.13	1.06	8800
PETN	Pentaerythritol Tetranitrate	MIL-P-387A	19.0 C, 2.5 H, 17.7 N, 60.8 O	6	17	C	U	225 D			62.7	145	173		8300	7680	1.54	1.77	Pressed			
RDX (Cyclonite)	Cyclotrimethylene Trinitramine	MIL-R-21723 MIL-R-13742 MIL-R-003988	16.3 C, 2.7 H, 37.8 N, 43.2 O	8	33	E	U	260 D	1.54	2.33	60.2	150	157		8180	8190	1.71	1.81	Pressed			
RDX/Wax 97/3		MIL-R-13758	97 RDX, 3 Wax	11	30	U		275			58.3				8240		1.51		Pressed			9200
Tetryl	2, 4, 6 - Trinitro-Phenylmethyl Nitramine	JAN-T-339	29.3 C, 1.7 H, 24.4 N, 44.6 O	8	26	C	U	257 I	1.58	2.01	54.2	130	125		7510	7375	1.62	1.73	Pressed			
Tetrytol 70/30			70 Tetryl, 30 TNT	11	28	U	U	320 I			53.2	120	121		7300	7342	1.61		Cast			
TNT	Trinitrotoluene	JAN-T-248	37.0 C, 2.2 H, 18.5 N, 42.3 O	14	100+	U	U	475 D	1.55 1.60	1.68 0.82	48.0	100	100	*[illegible], 1¼	6970	6790	1.57	1.65	Pressed Cast	1.00	1.00	8000
HMX (β Form)	Cyclotetramethylene Tetranitramine	MIL-H-45444	16.2 C, 2.7 H, 37.9 N, 43.2 O	10	17	E	U	327 D			59.3							1.94	Pressed			
Octol 75/25		MIL-O-45445	75 HMX, 25 TNT	13		U	U	350 F			62.1	116				8400	1.81		Cast			9200
	Column Number →		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE 2-5(U). COMPATIBILITY OF HIGH EXPLOSIVES WITH METALS AND OTHER MATERIALS [1]

Explosive \ Material	Aluminum	Brass: Brass	Brass: NRC coated	Brass: Shellac coated	Magnesium	Steel: Steel	Steel: Cadmium plated	Steel: Copper plated	Steel: Parkerized	Steel: Zinc plated	Steel: Stainless	Steel: Steel, acidproof black paint	Titanium	Black paint, acidproof	Cement Pettman
	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Amatol 50/50		S_m	VS_m	F_m	H_m‡	VH_m	C_m‡	H_m	C_m	H_m	F_m	F_m			
Mercury fulminate	F_m	F_m	F_m	F_m		F_m	F_m‡	F_m	F_m		F_m	F_m			
Pentolite	F_m	VS_m			S_m*	F_m	F_m	VS_m		F_m	F_m	F_m			
Picric acid	F_m	F_m	S_m	F_m		F_m	F_m‡	S_m	F_m	VS_m	F_m	F_m			
Tetrytol 65/35					F_m										
Tetrytol 75/25	F_m	VS_m			S_m*	VS_m	VS_m	VS_m		S_m	F_m	F_m			
Black powder	H_m	H_m	F_m	F_m	F_m*	H_m	F_m‡	VH_m	S_m	F_m	F_m	F_m			
Composition A-3	F_m	S_m			S_m*	S_m	F_m	S_m		S_m	F_m	F_m			
Composition B	F_m	S_m			S_m	VS_m	VS_m	S_m		S_m	F_m	F_m		M@100° U@120°	F_m
														U_x@120° M_x@90°	
Explosive D	F_m	F_m	F_m	F_m		C_m	F_m‡	VS_m	F_m	S_m	F_m	F_m			
Lead azide	F_m†	P_m	P_m	P_m	F_m*			P		VS_m					
PETN	VS_m	VS_m			S_m*	VS_m	VS_m	F_m		VS_m	F_m	F_m			
Picratol 52/48															
RDX	F_m	F_m	F_m	F_m		F_m	F_m‡	VS_m	F_m	F_m	F_m	F_m			
Tetryl	F_m	F_m	F_m	F_m		C_m	F_m‡	F_m	F_m	F_m	F_m	F_m			
Tetrytol 70/30					F_m										
TNT	F_m	F_m	F_m	F_m	H_m*	F_m	VS_m‡	VS_m	F_m	F_m	F_m	F_m		M	
Tritonal 80/20														M	

† 10 months ‡ 12 months * 18 months

Legend

F = favorable, no visible evidence of corrosion

VS = very slight corrosion, indicated by light tarnishing

S = slight corrosion, indicated by heavy tarnishing

H = heavy corrosion

VH = very heavy corrosion

C = considerable corrosion, indicated by pitting or rusting

P = prohibited

M = moderate reaction

U = undesirable reaction

W = wet sample

Subscript m = explosive reaction on metal

primers. Of the three, the percussion primer is the only type used in a fragmentation hand grenade.

2—10.2.1.1 (U) Percussion Primers

To ensure reliable delay element burning time, a grenade fuze must be obturated (sealed) to prevent the escape of gases during burning (par. 2—10.2.3). To maintain this gas-tight seal, the firing pin must not puncture or rupture the primer container when it strikes the container. A percussion primer, initiated by the impact of a blunt firing pin, provides a simple and reliable method of meeting this requirement.

2—10.2.1.2 (U) Percussion Primer Construction

A typical percussion primer consists of a cup, a thin layer of priming mix, a closing disk (cover), and an anvil (Fig. 2—19). Initiation occurs when the blunt firing pin pinches the priming mix between the cup and anvil. The output of a percussion primer is usually a flash or spit of flame, and is seldom a detonation.

The primer cup should be constructed of a ductile metal so that it will not rupture when it is struck by the firing pin. Brass is a common metal used for cups. Reference 28 describes design practices and specifies the standard dimensions, tolerances, materials, and finishes for primer cups. In general, all designs and construction should conform with Reference 28. However, it is not the intent of this reference to inhibit the development of new concepts; occasional departures from the prescribed practices may be necessary under special circumstances.

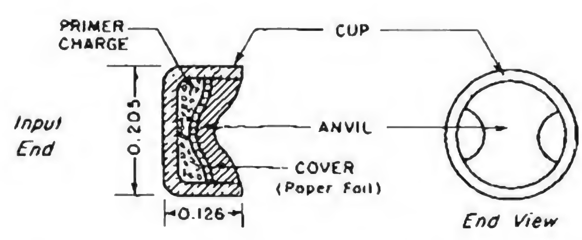

FIGURE 2—19(U)—TYPICAL PERCUSSION PRIMER [19]

The output end of a percussion primer is not sealed. The explosive is retained in the cup by a thin paper or metal cover.

The physical construction of a percussion primer can affect primer sensitivity in the following ways:

a. Cup Thickness. Primer sensitivity decreases as the thickness of the cup increases.

b. Cover Thickness. Primer sensitivity decreases as the thickness of the cover increases.

c. Anvil Movement. The anvil must be firmly attached. Any movement of the anvil can drastically reduce the sensitivity to the firing pin action, yet increase the sensitivity to shock and vibration.

d. Excentric Firing Pin Impact. Sensitivity is reduced for this type of impact.

Firing pin requirements are discussed in par. 2—9.2.2.

Loading pressure does not appreciably affect the input requirements of percussion primers. There is, of course, a direct relationship between the amount of explosive charge and the primer output.

2—10.2.1.3 (U) Priming Compositions

Table 2—6 lists the composition of common priming mixtures used by the military. The ingredients are given for seven standard primer compositions.

2—10.2.2 (U) Detonators

A detonator is a small, sensitive component that can initiate a high-order detonation in the next high explosive component of the train. In the case of the fragmentation grenade, the detonator fires the main charge (or the booster charge if one is used). A detonator is similar to a primer, except that its output is a detonation wave instead of a flame.

Detonators are classified according to the way they are initiated — i.e., flash

TABLE 2-6(U). COMMON PRIMING COMPOSITIONS[1]

	Composition (percent by weight)						
Ingredients	[1]FA70	[1]FA90	[2]PA100	[2]PA101	795	[3]NOL60	[3]NOL130
Lead Styphnate, Basic	–	–	–	53	39	60	40
Lead Styphnate, Normal	–	–	38	–	–	–	–
Barium Nitrate	–	–	39	22	44	25	20
Lead Azide	–	–	–	–	–	–	20
Tetracene	–	–	2	5	2	5	5
Lead Dioxide	–	–	5	–	–	–	–
Calcium Silicide	–	–	11	–	14	–	–
Aluminum Powder	–	–	–	10	–	–	–
Antimony Sulfide	17	12	5	10	–	10	15
Lead Sulphocyanate	25	25	–	–	–	–	–
PETN	–	10	–	–	–	–	–
TNT	5	–	–	–	–	–	–
Potassium Chlorate	52	53	–	–	–	–	–

[1]FA = Frankford Arsenal

[2]PA = Picatinny Arsenal

[3]NOL = Naval Ordnance Laboratory

detonators, stab detonators, and electric detonators. Of the three, flash detonators are used the most in fragmentation hand grenade design.

2—10.2.2.1 (U) *Flash Detonators*

Flash detonators are sensitive to heat. When they are initiated, a detonation wave is created at the output. Detonators for fragmentation grenades are initiated by heat from the delay element (par. 2—10.2.2).

A typical detonator consists of a cup; primary, intermediate, and base charges; and closing disks (Fig. 2—20(A)). The primary charge is located at the input of the detonator, and the base charge is located at the output. Usually, in a flash detonator, the primary and intermediate charges are combined so that, in effect, the detonator contains only two charges (Fig. 2—20(B)).

Aluminum and stainless steel are good cup materials for flash detonators. Gilding metal is also satisfactory, though it is not used for flash detonator cups as often as aluminum and stainless steel.

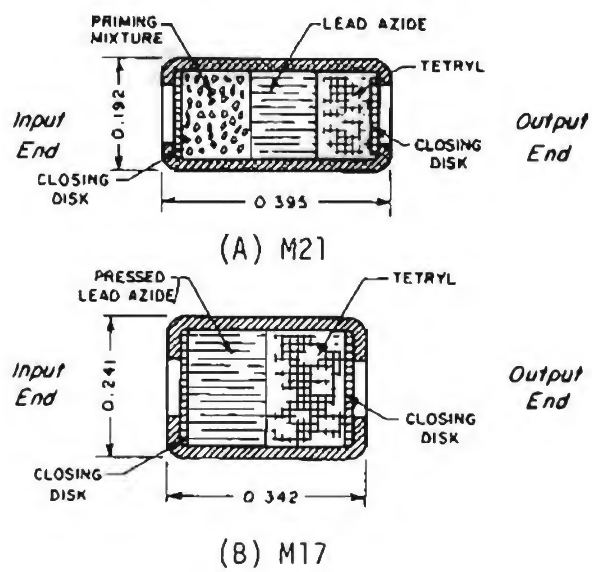

FIGURE 2—20(U)—TYPICAL FLASH DETONATORS[19]

The closing disks may be of metal or of paper. Both the material and the thickness of the material used to seal the input end of the cup affect primer sensitivity.

2—10.2.2.2(U) Explosives for Detonators

Most flash detonators contain only a primary charge and a base charge, although in the past most also contained an intermediate charge (Fig. 2—20). Since the trend is toward detonators containing two charges, only those types are discussed here.

a. Primary Charge. Primary high explosives (par. 2—10.1) are used as the primary charge. The properties that promote the growth of detonation have not been quantitatively defined. However, lead azide appears to be so superior to other explosives that it is the only one used in current fuze detonators (excluding bridgewire applications). At first glance, certain other explosives might appear to be as suitable as, or even superior to, lead azide; but on close analysis, lead azide has better *overall* characteristics in this application. The fact that flash detonators are ignited by rather diffusely distributed heat might lead to the conclusion that such explosives as tetryl and PETN, which have relatively low ignition temperatures, would be effective at the input end of a flash detonator. However, these explosives are much less sensitive to heat *pulses* of short duration than is lead azide.

Lead styphnate is more sensitive than lead azide, however it cannot be used to detonate tetryl, TNT, PETN, or RDX. Silver azide appears superior to lead azide in some respects, but it may never be available in sufficient quantities.

b. Base Charge. A secondary high explosive (par. 2—10.1) is usually used as the base charge of a flash detonator. Both tetryl and RDX have proven to be good base charges for flash detonators, and in most cases are the only explosives considered for this purpose.

2—10.2.2.3(U) General Design Considerations

The total energy released by a flash detonator is the sum of the heat of detonation and the quantity of the various explosives used. Of this total energy, only the energy from the high-order detonation is the effective output. In general, this includes the base charge and part of the primary charge. Where the primary charge is dextrinated lead azide, the portion that detonates high-order can vary appreciably with loading density, confinement, and lot-to-lot variations in the lead azide. The azide that actually detonates must be sufficient to initiate the base charge. A rule of thumb calls for a 0.10-in. minimum column height.

The growth of detonation is most rapid in explosives loaded at densities well below those usually used in military applications. But, the effective output of stable detonating explosives increases sharply with density. Therefore, a given quantity of explosive charge has a maximum effective output at a particular optimum density. This optimum density is affected by the composition and particle size of the explosive, the energy with which it is initiated, and the dimensions and confinement of the explosive. For conditions usually encountered in designing detonators for fuzes, the optimum density for dextrinated lead azide and normally used base charge explosives is obtained by loading at between 10,000 and 20,000 psi. For other lead azides — such as PVA, colloidal, and RD1333 — loading pressures are much higher. These are given in Fig. 2—21.

Confinement of the explosives is an important factor in both the growth of detonation and the effective output resulting from a stable detonation. In the early stages of detonation, the detonator case, closure, and the surrounding structure should be considered as a container of high-pressure gases. During these early stages, tightness — i. e., the absence of leaks — is the most important factor. As the growth of detonation progresses, the strength of the container becomes more important, while the importance of leaks diminishes. As the detonation approaches its stable rate, the pressure exceeds the bursting strength of any practical container and confinement becomes a matter of inertia. In relatively thin-walled containers, the confinement afforded by the inertia of the container is related to the weight ratio of the charge to case C/W.

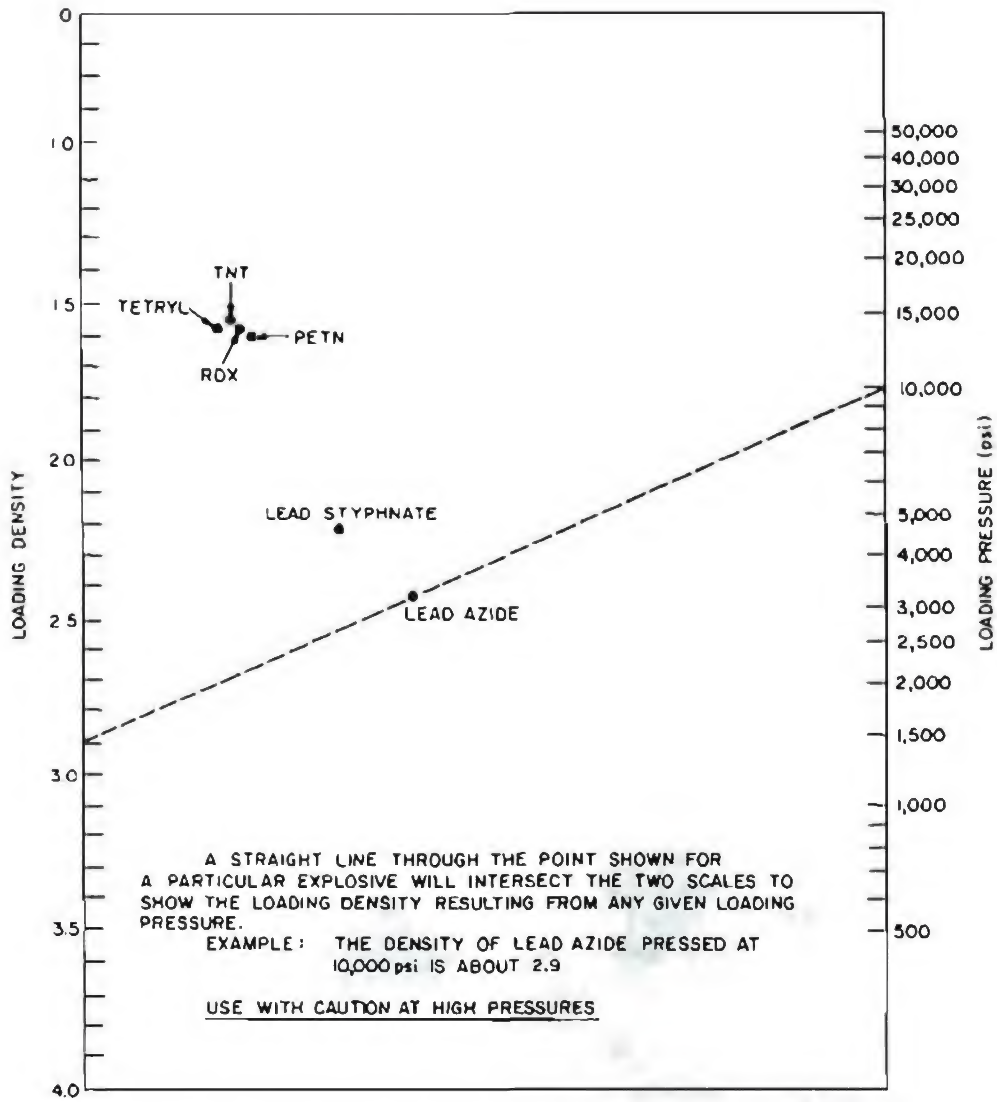

FIGURE 2—21(U)—LOADING PRESSURE VERSUS DENSITY NOMOGRAPH [1]

2—10.2.3(U) Delay Elements

Delay elements are incorporated into hand grenade fuzes to provide time for the grenade to reach the target before detonating. The most typical delay time required for fragmentation hand grenades is about 4.5 sec.

The delay element can be a mechanical or electrical device, but simple and inexpensive delay columns of explosive materials are the ones used in current fragmentation hand grenades. Generally, these delay columns burn like a cigarette, i. e., they are ignited at one end and burn linearly.

Delay elements are classified as either vented or obturated. Vented delays allow the gases generated by the initiator and delay element to escape. Obturated delays are inherently independent of the effects of ambient pressure and humidity. Obturation also helps in the design of shorter delay times because the resulting rise in pressure increases the burning rate. Further, because the delay is protected from the ambient atmosphere, more reliable and consistent delay times can be achieved. For these reasons, modern U. S. fragmentation hand grenades use obturated delays exclusively.

2—10.2.3.1 (U) Delay Compositions

Explosives for delay elements are classified as either gas-producing delay charges or gasless delay charges. Each type is discussed briefly in the paragraphs which follow.

2—10.2.3.2 (U) Gas-producing Delay Charges

Black powder is the largest class of gas-producing delays. Black powder is easily loaded and ignited. It is relatively inexpensive and is available in a variety of granulations. Black powder is affected by moisture and atmospheric pressure, but this is not a problem in the design of obturated delay elements. However, black powders do produce considerable quantities of gas, and an expansion chamber must be provided between the top of the delay column and the primer (Fig. 2—10).

2—10.2.3.3 (U) Gasless Delay Charges

Gasless delay mixtures are basically thermit-type mixtures of a metallic fuel and an oxidizing agent. The term gasless must not be taken literally; gasless delay compositions do produce some gas, but chiefly as the result of impurities.

Table 2—7 lists gasless delay compositions in current use. The ranges listed for the compositions allow for adjustment of burning rates over wide ranges.

2—10.2.4 (U) Relays

A relay (Fig. 2—22) is a small explosive component that amplifies a relatively weak explosive impulse and applies it to the next component in the explosive train. In most fragmentation grenades, the relay is usually the last charge increment in the delay column (Fig. 2—23).

Nearly all relays are loaded with lead azide. The relay cups are almost always made from aluminum. Since a relay is usually the last charge increment in a grenade delay column, its diameter is determined by the diameter of the column.

TABLE 2-7(U). GASLESS DELAY COMPOSITIONS* IN CURRENT USE [1]

Fuel	Oxidant		Inert
Boron	Barium Chromate	Chromic Oxide	None
4 to 11	89 to 96	–	
13 to 15	40 to 44	41 to 46	
Manganese	Barium Chromate	Lead Chromate	None
45 to 30	0 to 40	15 to 70	
20 to 50	70 to 40	10	None
Molybdenum	Barium Chromate	Potassium Perchlorate	
20 to 30	70 to 60	10	
Ni-Zr Alloy	Barium Chromate 60	Potassium Perchlorate 14	None
Ni-Zr Mix	Barium Chromate	Potassium Perchlorate	None
5/31	22	42	
5/17	70	8	
Selenium	Barium Peroxide	–	Talc 0.5 (added)
84	16		
Selenium	BaO_2	–	Tin/lead Alloy Powder (15/85)
20	80		20
Silicon	Red Lead	–	Celite max. 8 parts by weight
20	80		
Tungsten	Barium Chromate	Potassium Perchlorate	Diatomaceous Earth
27 to 39	59 to 46	9.6	5 to 12
39 to 87	46 to 5	4.8	3 to 10
Zirconium	Lead Dioxide	–	None
28	72		

*Percentage by weight

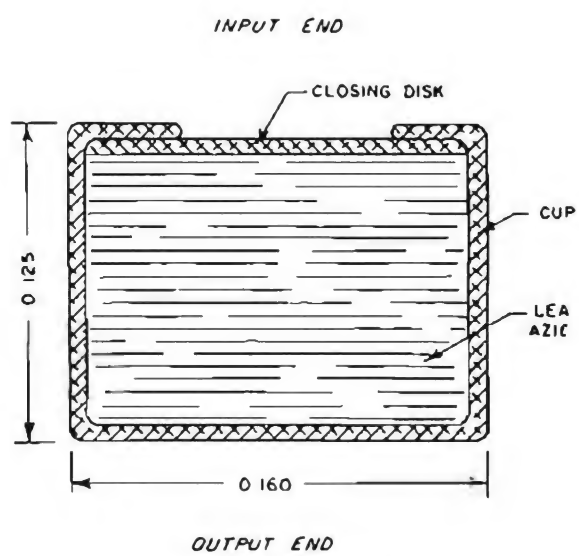

FIGURE 2—22(U)—TYPICAL RELAY [19]

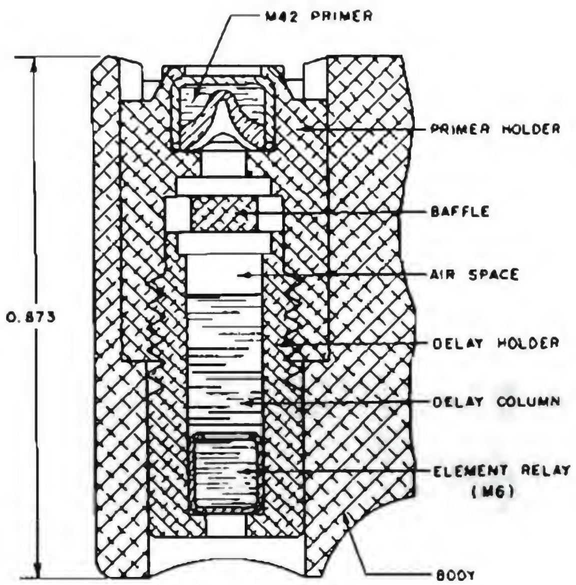

FIGURE 2—23(U)—RELAY USED AS LAST CHARGE INCREMENT IN A DELAY COLUMN[19]

2—10.2.5(U) Main Charges

The purpose of the explosive train of a fragmentation hand grenade is achieved by the effective detonation of the main charge. The initiation of a main charge is not always a matter of simple "fire-misfire" reliability. All main charge explosives are capable of a low-order detonation even though the probability of complete failure is low. Thus, the problem of main charge initiation is that of reliably initiating high-order detonation.

The characteristics of various high explosives used for main charges are given earlier in par. 2—10.1. Explosives considerations involved in the design of fragmentation hand grenades are discussed in par. 2—6.2.

SECTION III (U)

CHEMICAL HAND GRENADES

2—11(U) GENERAL

The three types of chemical grenades in general use are: (1) irritant grenades, (2) incendiary grenades, and (3) smoke grenades. Irritant grenades are used almost exclusively for riot control. Occasionally, they might be used to harass an enemy. Incendiary grenades burn at a very high temperature and are used primarily to destroy equipment. Smoke grenades are used for screening or signaling.

2—12(U) IRRITANT GRENADES

2—12.1(U) GENERAL REQUIREMENTS

An irritant grenade must temporarily incapacitate a rioter to prevent him from continuing his activity. Irritant grenades must be safe to handle and throw by troops wearing gas masks; they must not flame, spark, or explode when they are thrown, and their ability to ignite flammable materials must be minimized. Furthermore, an irritant grenade must meet the environmental requirements listed in par. 2—2.

2—12.2(U) AGENTS

2—12.2.1(U) Dispersal

Agents used in irritant grenades must be of a type that can be easily dispersed into the air. The grenade should be designed so that the maximum concentration of agent per unit weight of grenade is generated and dispersed. To date, the two most effective methods of dispersing the agent are:

(1) the agent is mixed with combustible composition that is ignited when the grenade is thrown. The heat of combustion causes the agent to disperse into the air by sublimation. The grenade casing remains intact; the gases are dispersed through small orifices in the casing.

(2) the agent, in micropulverized form, is dispersed instantaneously by the explosion of a detonator. The explosion bursts the grenade casing, and the agent is dispersed as a heavy concentration of small particles.

No matter which method is used, the dispersed agent is nonpersistent, i.e., it is quickly dissipated by the wind. For a given amount of agent, the burning-type grenade has a longer dispersal time; dispersal times up to one minute are typical. However, the bursting-type produces a higher concentration of the agent. Furthermore, the bursting-type grenade cannot be kicked aside or picked up and thrown back at the thrower, which is possible with the burning-type if its dispersal period is too long.

2—12.2.2(U) Types of Agents

The three major types of agents used in irritant grenades are:

(1) chloroacetophenone (CN)

(2) diphenylaminechloroarsine (DM)

(3) orthochlorobenzylidenemalonitrile (CS)

CN is a lachrymator, which causes eye irritation and tearing ("tear gas"). It is also an irritant to the upper respiratory tract. The effects of CN are relatively mild, and wear off soon after exposure.

DM is a sternutator, which causes violent sneezing, intense headaches, nausea, and temporary debility.

CS is a lachrymator that produces severe burning sensations in the nose, throat, and lungs. It is much more quick-acting than both CN and DM.

Both CN and DM agents are sometimes used in the same grenade (par. 2—12.3.2).

In addition to the agent, the filler or main charge of a burning-type irritant grenade requires a fuel-oxidizer mixture and a starter mixture. The fuel provides the combustion necessary to disperse the agent. Oxygen for combustion is provided by the oxidizer. The starter mixture ignites the fuel-oxidizer mixture.

Generally, the agent and the fuel-oxidizer mixture are pressed to the desired shape, which is usually cylindrical, and then coated with the starter mixture. However, in cases where the agent and the fuel-oxidizer mixture used tend to react with one another, the two must be physically separated. This can be accomplished by encapsulating the agent and embedding it in the fuel-oxidizer mixture before pressing (Fig. 2—26).

Tables 2—8, 2—9, and 2—10 list the compositions generally used in burning-type irritant grenades. Compositions for bursting-type irritant grenades are given in Table 2—11.

2—12.3(U) DESIGN CONSIDERATIONS

2—12.3.1(U) General

Irritant grenade compositions and methods of dispersal are described in par. 2—12.2. Considerations in designing the grenade itself, and in packaging the composition are discussed in the paragraphs which follow.

2—12.3.2(U) Burning-type Irritant Grenade

Designing the canister, or casing, for a burning-type irritant grenade is relatively simple. A canister constructed of thin rolled steel is satisfactory. All present-day burning-type irritant grenades use 28 gage steel. The dimensions of the canister must be such that it can be easily held and thrown. Past experience indicates that a canister having a diameter between 2-1/2 and 3 in. and a length between 4 and 5 in. is satisfactory. Emission holes must be provided to allow the agent to disperse. These holes must be sealed to protect the fill from the effects of moisture. Adhesive tape, coated with lacquer, is satisfactory for this purpose.

Fig. 2—24 shows a typical burning-type irritant grenade. The agent is dispersed through an emission hole in the bottom of the canister. The axial hole in the fill increases the burning surface of the composition and provides venting. The area of the axial hole is a function of the mix

TABLE 2–8(U). CN IRRITANT GRENADE COMPOSITION

CN Mixture	*	IGNITER COMPOSITION	*	AGENT/IGNITER PROPORTION
Chloroacetophenone	29	Potassium Nitrate	70.5	Igniter is poured into grenade as a slurry and then poured out in the manner of a ceramic slip casting. Approximately 5 grams (dry basis) is retained.
Diatomaceous Earth	5	Charcoal	29.5	
Sucrose	17			
Potassium Chlorate	24			
Potassium Bicarbonate	25			
		Mix with:		
Press at: 5000-7500 lb		Nitrocellulose	4 parts	
dead load		Acetone	96 parts	

* Parts by weight

TABLE 2–9(U). DM IRRITANT GRENADE COMPOSITION

DM Mixture	*	IGNITER COMPOSITION	*	AGENT/IGNITER PROPORTION
Diphenylaminechloroarsine	52.5	Potassium Nitrate	70.5	Igniter is poured into grenade in a slurry and poured out in the manner of a ceramic slip casting. Approximately 5 grams (dry basis) is retained.
Potassium Chlorate	25.5	Charcoal	29.5	
Sucrose	17			
Magnesium Oxide	5			
Press at: 5000-7500 lb		Mix with:		
dead load		Nitrocellulose	4 parts	
		Acetone	96 parts	

*Parts by weight

TABLE 2–10(U). CS (ENCAPSULATED) IRRITANT GRENADE COMPOSITION

CS Mixture	*	STARTER MIXTURE	*	AGENT/IGNITER PROPORTION*
Orthochlorobenzylidenemalonitrile -- in 92 #00 gelatin capsules	– –	Potassium nitrate Charcoal	70.5 29.5	907/1209
Potassium Chlorate } 165 grams	40			
Sucrose } 165 grams	28			
Magnesium Carbonate } 165 grams	32			
Press at: 5000-7500 lb		Mix with:		
dead load		Nitrocellulose	8 parts	
		Acetone	92 parts	

*Parts by weight

TABLE 2-11(U). COMPOSITIONS FOR BURSTING-TYPE IRRITANT GRENADES

MIXTURE	%
CS	95
Aerogel	5
DM	95
Aerogel	5
CN	92.0 ± 0.5
Magnesium oxide	8.0 ± 0.5

being used and must be determined in each case.

In some cases, a single grenade may be required to contain more than one type of agent. If the agents are incompatible, they must be kept physically separated within the grenade. This can be accomplished by loading the agents into separate containers that are ignited simultaneously when the grenade is fired. Fig. 2—25 shows a grenade loaded with CN and DM agents which tend to react with one another when in contact.

If the agent tends to react with the fuel-oxidizer mix, the agent can be loaded into gelatin capsules which are then embedded in the mix. Fig. 2—26 shows a CS irritant grenade loaded in this manner.

2—12.3.3(U) Bursting-type Irritant Grenade

The agent in the bursting-type grenade is dispersed as a cloud of micropulverized particles. The casing of the grenade is made in two halves which are blown apart by the detonator. This releases the micropulverized particles, essentially as an aerosol, and the force of the detonation disperses them. Since the principal purpose of the detonator is to open the casing, no additional bursting charge is used. The most uniform agent distribution is obtained by using a special casing. The casing must be designed so that: (1) it readily breaks apart when the detonator explodes and (2) it will not fragment when the grenade detonates. This last requirement is very important because irritant grenades are used primarily for riot control, and the

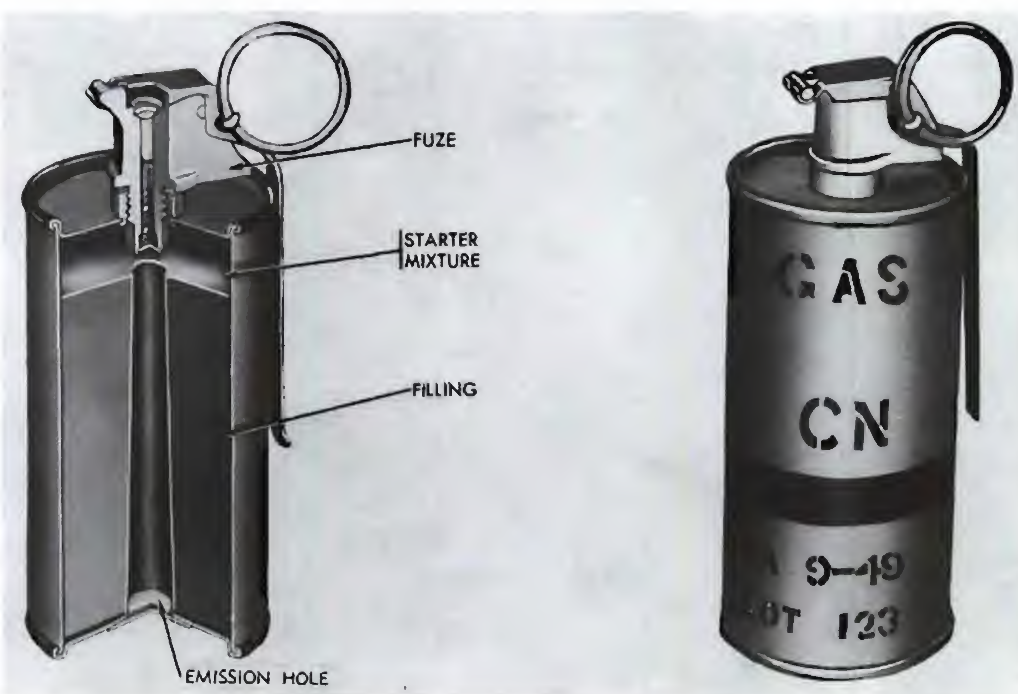

FIGURE 2—24(U)—TYPICAL BURNING-TYPE IRRITANT GRENADE

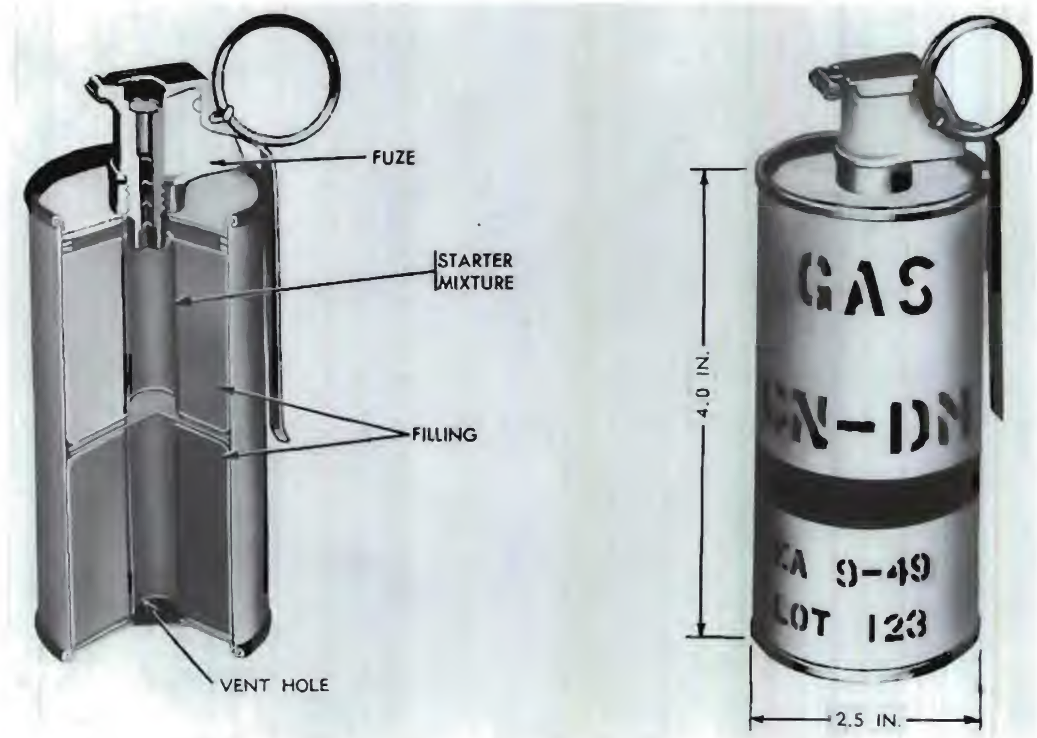

FIGURE 2—25(U)—IRRITANT GRENADE LOADED WITH CN AND DM AGENTS

probability of injuring a rioter must be kept to a minimum. Fig. 2—27 illustrates the most common method of meeting these requirements. A spherical plastic casing, consisting of hemispherical sections, breaks in half at detonation. Since the casing breaks up along the junction of the two sections, essentially no fragments are produced.

2—12.3.4(U) Fuzing

Pyrotechnic time delay fuzes, because of their low cost and acceptable performance, are used in all present-day irritant hand grenades. Design considerations for striker assembly and safety devices for a burning-type irritant grenade are the same as those for the fragmentation hand grenade, and are covered in pars. 2—9.2.1 and 2—9.2.2, respectively. The explosive train for a burning-type irritant grenade is relatively simple, requiring only a percussion primer, a pyrotechnic delay column, and a flash base charge. The delay column must be designed so that the delay is long enough to protect the thrower, yet short enough to minimize the possibility of a rioter picking up the grenade and tossing it back. Time delays in the range of 1-1/2 to 3 sec meet this requirement.

Although the bursting-type irritant grenade uses a pyrotechnic time delay fuze also, its fuze and explosive train differ from those used in the burning-type grenade. A spherical casing does not readily lend itself to the use of a striker assembly or a safety lever of the types used with spherical and barrel-shaped hand grenades. From a design and construction standpoint, a plunger-type fuze (Fig. 2—27) is more adaptable to a spherical grenade. This type of fuze employs a spring-driven arming sleeve which is held down by the thrower's thumb. The arming sleeve is released when the grenade is thrown, thereby allowing the arming pin to fly free. The spring then drives the detonator, which is contained in the lower half sleeve, down onto the firing pin to initiate grenade detonation.

The bursting charge of a bursting-type grenade need only be great enough to

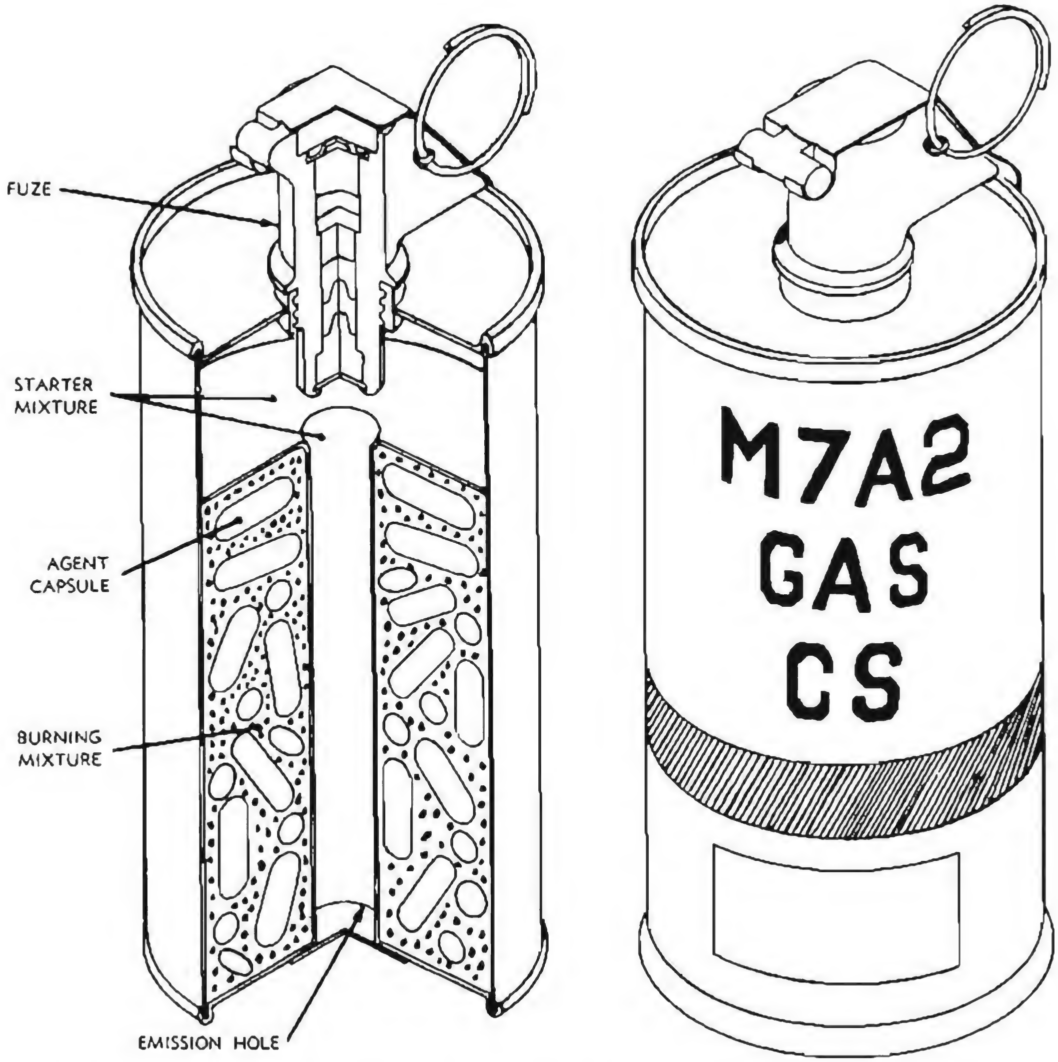

FIGURE 2—26(U)—IRRITANT GRENADE WITH CS AGENT LOADED INTO GELATIN CAPSULES

burst the casing and disseminate the agent. A main explosive charge is not needed to burst the casing and disseminate the agent; the explosive output of a detonator can be used for this purpose. A delay-type detonator — consisting of a primer, delay column, and the detonator explosive charges (Fig. 2—28) — is ideally suited to burst-type irritant grenades. Although vented delay detonators have been used in the past, the use, or design, of a nonvented delay detonator is desirable. Surveillance tests of M25 irritant grenades with vented detonators uncovered a large quantity of duds, which were believed to have been caused by permeation of the delay composition during storage[29]. Nonvented delay detonators, employing a gasless delay composition, will greatly improve the storage characteristics of delay detonators. Reference 29 gives design details for a nonvented-type delay detonator.

2—13(U) INCENDIARY GRENADES

2—13.1(U) GENERAL

Incendiary hand grenades provide concentrated heat for destroying enemy equipment or for destroying friendly equipment in danger of falling into enemy hands. An incendiary hand grenade may also be used as a booby trapping device.

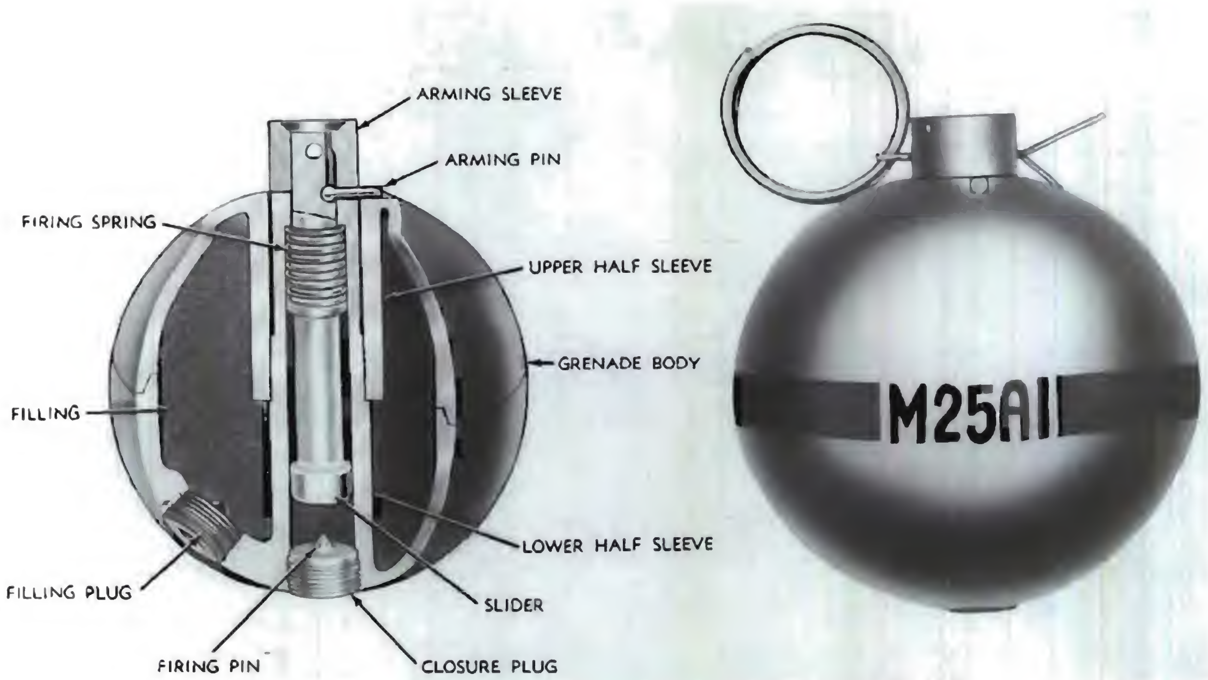

FIGURE 2—27(U)—TYPICAL BURST-TYPE IRRITANT GRENADE

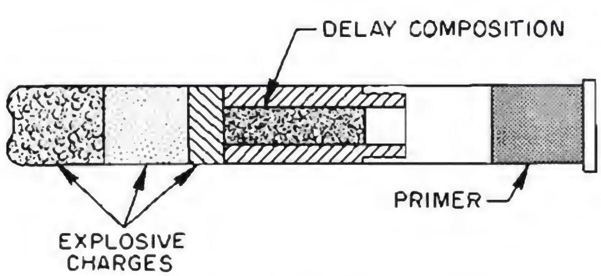

FIGURE 2—28(U)—DELAY-TYPE DETONATOR

2—13.2(U) PYROTECHNIC COMPOSITION

A complete description of incendiary mixtures is given in Reference 30. In present-day incendiary grenades, thermate is used as the pyrotechnic composition. Besides starting fires, thermate, because of its high burning temperature, is capable of melting and/or distorting metals such as iron and steel. The thermate composition used for present-day incendiary grenades is listed in Table 2—12. The M14 incendiary grenade (Fig. 2—29) contains 26 oz of thermate, and burns for about 40 sec at 4300°F[31]. The thermate charge is capable of burning through a 1/4-in. thick steel plate.

2—13.3(U) DESIGN CONSIDERATIONS

Except for the type of composition (par. 2—13.2) and the manner in which the composition is loaded, the design of an incendiary grenade is the same as that for a burning-type irritant grenade. The same type of canister (par. 2—12.3.2) and the same method of fuzing (par. 2—12.3.4) are used in both grenades. However, while the starter mixture is coated on the surfaces of an irritant grenade fill, it is pressed into a separate cavity in the incendiary grenade. Unlike the fill of an irritant grenade, the pyrotechnic fill of an incendiary grenade, once ignited, will burn through until the supply is depleted.

2—14(U) SMOKE GRENADES

2—14.1(U) GENERAL

Smoke hand grenades are used primarily for signaling and screening. White and

TABLE 2-12(U). INCENDIARY GRENADE COMPOSITION

THERMATE (TH3)	
INGREDIENT AND SPECIFICATION	PARTS BY WEIGHT
Aluminum, Type II, Mil-A-512, Grade D, Class 5	16
Aluminum, Type II, Mil-A-512, Grade C, Class 4	9
Iron Oxide, Mil-I-275, Black, Class B	44
Barium Nitrate, Mil-B-162, Class 5	29
Sulfur, Mil-S-00487, Grade E	2
Castor oil (binder)	not to exceed 0.2% by weight

STARTER MIXTURE *	
INGREDIENT	PARTS BY WEIGHT
Red Lead	54.2
Manganese	34.2
Silicon	11.6
Nitrocellulose (binder)	8.0
Acetone (binder)	92.00

* 25 grams of starter mixture are added to grenade

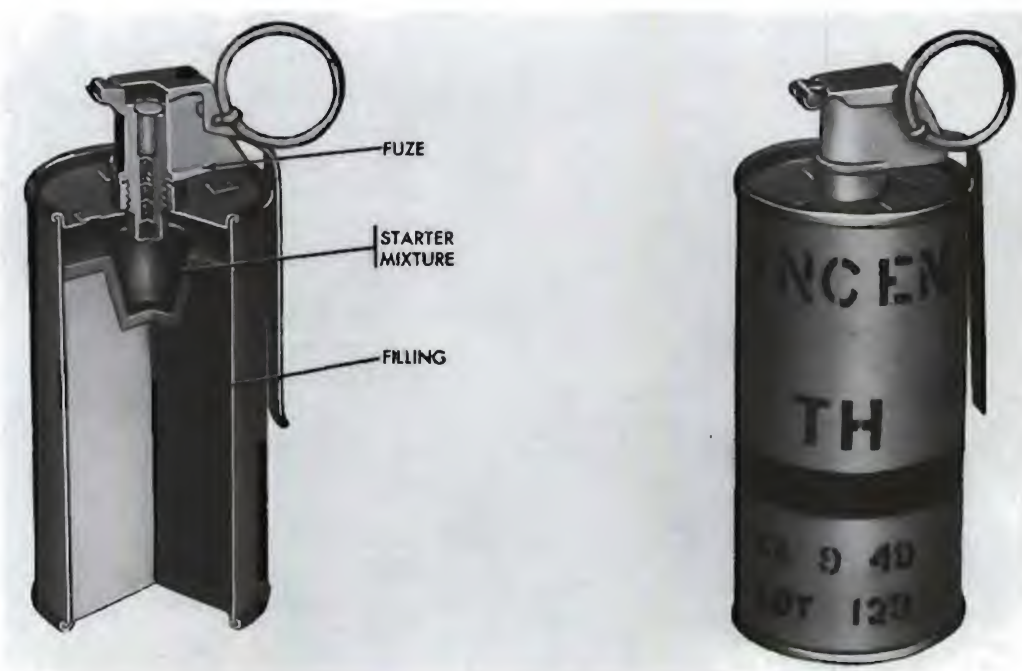

FIGURE 2 — 29(U) — M14 INCENDIARY GRENADE

colored smokes are used for signaling, usually to identify friendly troops. For screening, white smoke is used exclusively.

2—14.2 (U) SMOKE COMPOSITIONS

2—14.2.1 (U) Dispersal

All present-day smoke hand grenades used for signaling are of the burning type; depending upon the particular design, they disperse smoke for about 50 to 120 sec. There is no requirement for a bursting-type smoke hand grenade for signaling purposes. Bursting-type smoke munitions are used primarily as target indicators for friendly forces providing artillery and air support. This support would normally not be provided within 40 to 50 yd of friendly troops, which is the maximum distance that a hand grenade can be thrown.

For screening purposes, a smoke hand grenade must produce a low-lying, dense smoke cloud instantly. Therefore, a bursting-type grenade is required.

2—14.2.2 (U) Types of Compositions

Smoke compositions for green, red, yellow, and violet smoke hand grenades are given in Table 2—13. The composition for white smoke is given in Table 2—14.

TABLE 2—13(U). COLORED SMOKE HAND GRENADE COMPOSITIONS

SMOKE MIXTURE

INGREDIENT AND SPECIFICATION	PARTS BY WEIGHT			
	VIOLET	RED	YELLOW	GREEN
Dye	42 (MIL-D-3691)	40 (MIL-D-3718)	14 (MIL-D-50029)	4 (MIL-D-50029)
Sodium Bicarbonate O-S-00576	24	25	33	22.6
Potassium Chlorate Mil-P-150, Grade B, Class 7	25	26	20	27
Sulfur, Mil-S-00487 Grade E	9	9	8.5	10.4
Benzanthrone, Mil-D-50074	–	–	24.5	8
Dye, Solvent, Green 3, Mil-D-3277	–	–	–	28

Press at 5000 – 5500 psi

IMPREGNATING MIXTURE

INGREDIENT	PARTS BY WEIGHT
Potassium Nitrate	152
Charcoal	65
Gum Arabic (dissolved in water 8:92)	9

STARTER MIXTURE

INGREDIENTS	PARTS BY WEIGHT
Potassium Nitrate	417
Silicon	309
Charcoal	46
Nitrocellulose (binder)	13
Acetone (binder)	317

TABLE 2–14(U). WHITE BURNING SMOKE (HC) COMPOSITION

Smoke Mixture	*	Starter Mixture	*	Agent/Igniter Proportion
Hexachloroethane	44.53	Silicon	26	
Zinc Oxide	46.47	Potassium Nitrate	35	25 grams of starter mixture are used
		Charcoal	4	
Aluminum Powder (Amount required to obtain burning time)	---	Iron Oxide	22	
		Aluminum Powder	13	
		Nitrocellulose (binder)	6	
		Acetone (binder)	94	

* Parts by weight

Three parameters of a colored smoke grenade that are of primary concern to the designer are: (1) burning time, (2) burning temperature, and (3) burning pressure. Tests on the M18 colored smoke hand grenade[32], which is the standard U. S. colored smoke grenade, indicate that these parameters sometimes vary considerably for different colors and even for any one particular color. The most noticeable difference among the grenades was in burning temperature (Table 2—15). Red and yellow grenades burn cooler than green and violet grenades. Furthermore, visual observation indicates that green and violet grenades sometimes burn erratically, whereas red and yellow grenades burn more uniformly.

Average grenade burning times, and the range of burning times for each color of smoke are given in Table 2—16. Normal burning pressures for each colored smoke grenade are given in Table 2—17. The normal burning pressure for all of the grenades is 1 psi. However, during tests, the orifices of the green and the violet grenade sometimes became plugged, which caused the internal pressure of these grenades to rise to about 20 psi. The plugging resulted from thick liquid reaction products flowing through the orifices during combustion. When the internal pressure reached about 20 psi, these reaction products were blown through the orifices to distances up to 10 ft. The pressure then dropped to normal until the orifice became blocked again.

TABLE 2–15(U). BURNING TEMPERATURE OF COLORED SMOKE HAND GRENADES[32]

Color	No. of Samples	Burning-Temperature Range (°C) [1]
Green	4	580-750
Red	5	440-610
Yellow	4	420-510
Violet	5	630-780

[1] The burning temperature variation for individual grenades was about 50°C.

Reference 32 gives methods for directly measuring burning temperature, burning pressure, and weight loss during burning. Burning time can be calculated from either pressure or weight-loss data.

The only standard bursting-type smoke hand grenade in use contains 15 oz white phosphorous (WP). White phosphorous ignites on contact with the air and produces a dense white cloud when dispersed from a grenade by a high explosive. Because WP ignites and burns on contact with the air, WP grenades may also be used for incendiary and antipersonnel purposes.

2—14.3(U) DESIGN CONSIDERATIONS

2—14.3.1 (U) Burning-type Smoke Grenades

Design of the canister, or casing, for a burning-type colored smoke grenade is the

TABLE 2-16(U). BURNING TIME OF COLORED SMOKE HAND GRENADES[32]

Color	No. of Samples	Range of Burning Times (Sec)	Average Burning Time (Sec)
Green	7	45-57	52
Red	8	52-83	66
Yellow	8	51-60	55
Violet	7	47-71	59

TABLE 2-17(U). INTERNAL PRESSURE OF COLORED SMOKE HAND GRENADES[32]

Color	No. of Samples	Pressure Range During Normal Burning (psi)
Green	4	0.05 – 1.0
Red	6	0.04 – 0.41
Yellow	6	0.03 – 0.6
Violet	4	0.03 – 1.0

same as that for the burning-type irritant grenade (par. 2—12.3.2). For present-day applications, 28 gage steel has proven a satisfactory casing material. Like burning-type irritant grenades, burning-type colored smoke grenades require that the filler composition be drilled out and the surface coated with the starter mixture to provide sufficient burning surface and venting.

The standard U. S. colored smoke hand grenade, the M18, is shown in Fig. 2—30. This grenade may be loaded with a red, green, yellow, or violet smoke composition. Burning times, and other data, for each of these compositions are given in par. 2—14.2.2.

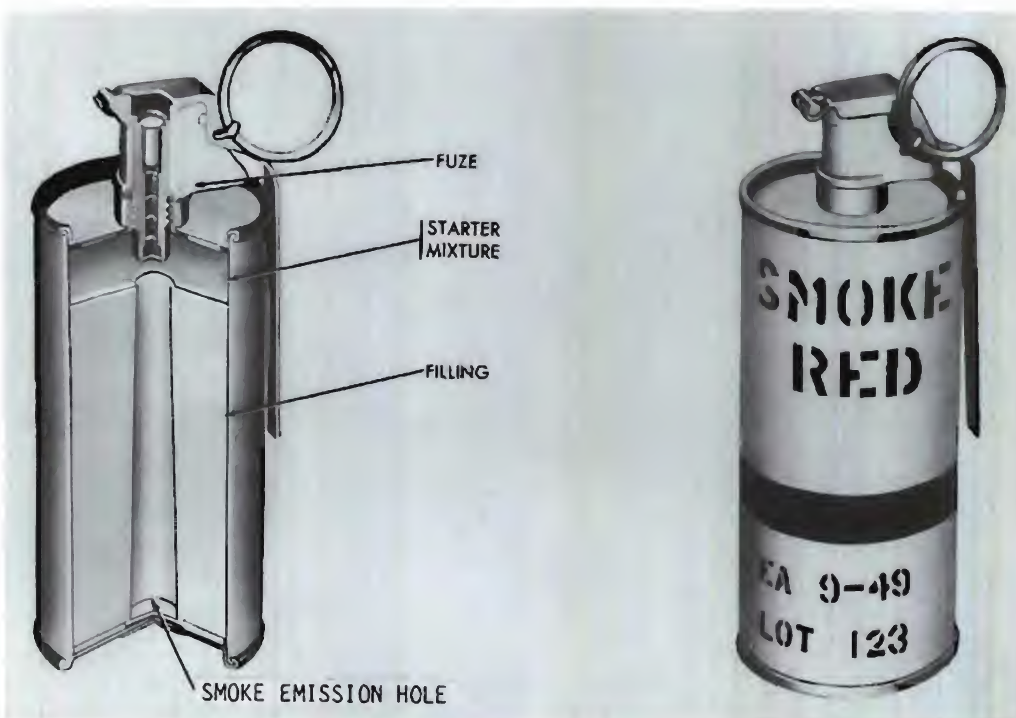

FIGURE 2—30(U)—M18 COLORED SMOKE HAND GRENADE

The canister for the white smoke (HC) hand grenade is the same as that for the burning-type irritant grenade. However, for the HC smoke composition, it is not necessary to drill out the center of the filler. Instead, the starter mixture can be loaded into a separate cavity, as shown in Fig. 2—31.

2—14.3.2(U) Bursting-type Smoke (WP) Grenades

White phosphorous ignites on contact with air. Therefore, the grenade must be designed so that it is leakproof to prevent air from entering the casing and filler from leaking out of it. Since leaks occur at joints, joints should be eliminated wherever possible. A "tin can" type of casing, such as that used for all present-day burning-type grenades, does not provide adequate sealing for a WP grenade. Better sealing can be obtained by designing the casing so that its sides and bottom are of one piece construction (Fig. 2—32). This avoids having to use a separate bottom cover and, consequently, eliminates a major joint through which leakage might occur.

Crimped joints do not provide adequate sealing for WP grenades. The top cover should be designed for a force fit. Particular care must be taken to design the fuze and the fuze well so that no leakage can occur.

Fig. 2—32 shows the construction of older-type WP grenades. The most recent type, shown in Fig. 2—33, employs a scored steel casing. A scored casing breaks up more uniformly and more quickly, and results in a better dissemination of the WP filler. Furthermore, the resulting case fragments enhance the antipersonnel effects of the grenade.

2—14.3.3(U) Fuzing

Pyrotechnic time delay fuzes have proven satisfactory for use with both the burning-type and the bursting-type smoke grenade. Design considerations for fuzes used with burning-type smoke grenades are the same as those for burning-type irritant grenades (par. 2—12.3.4).

The fuze and explosive train for a bursting-type smoke (WP) grenade are the same as for a fragmentation hand grenade, and

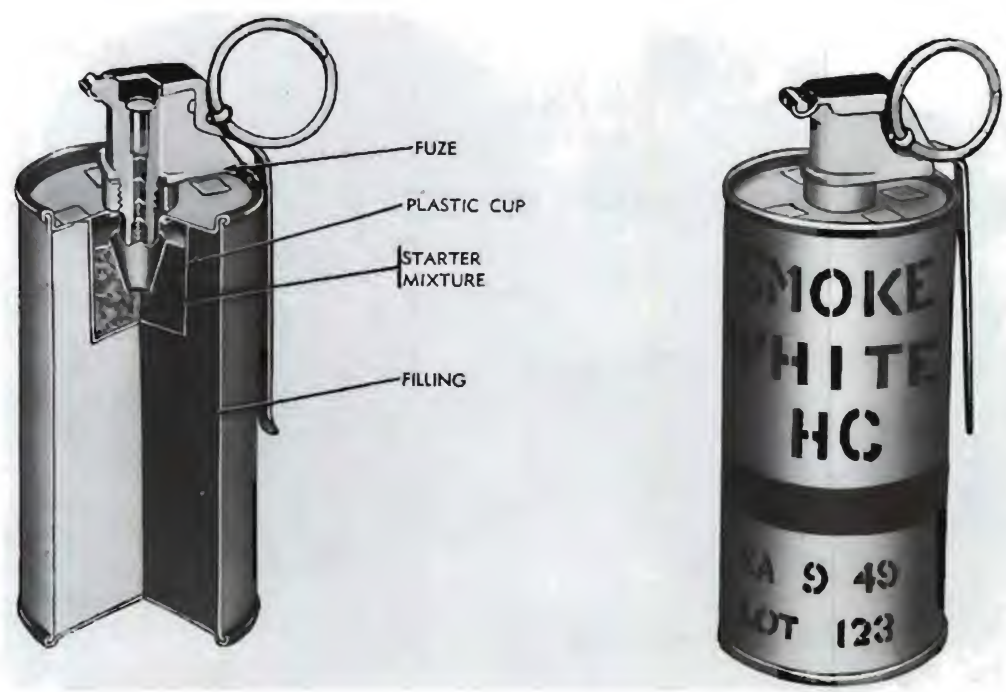

FIGURE 2—31(U)—WHITE SMOKE (HC) GRENADE

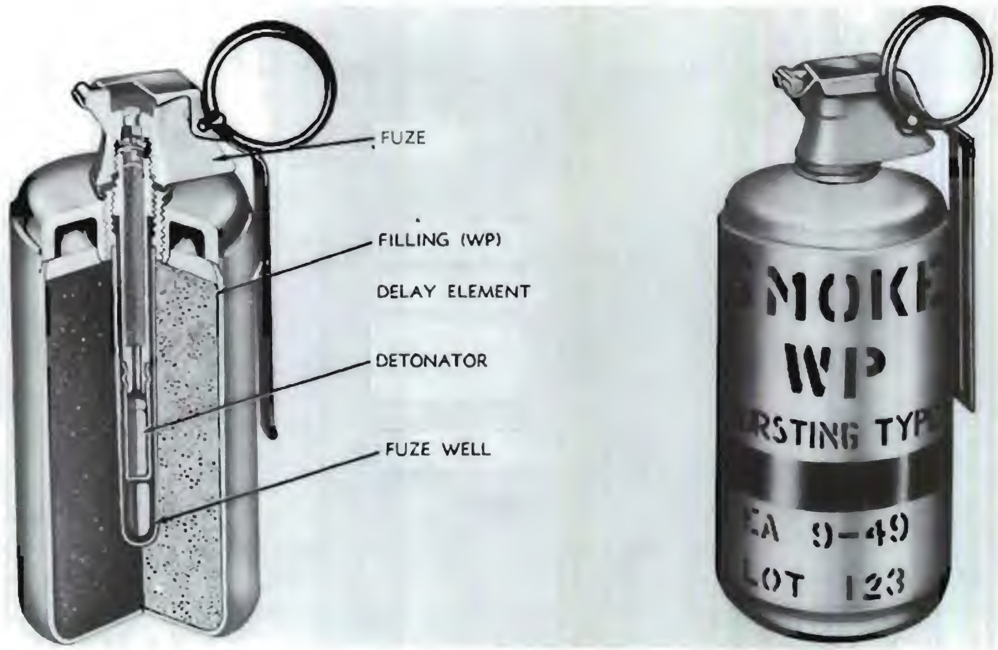

FIGURE 2 — 32(U) — WP SMOKE HAND GRENADE

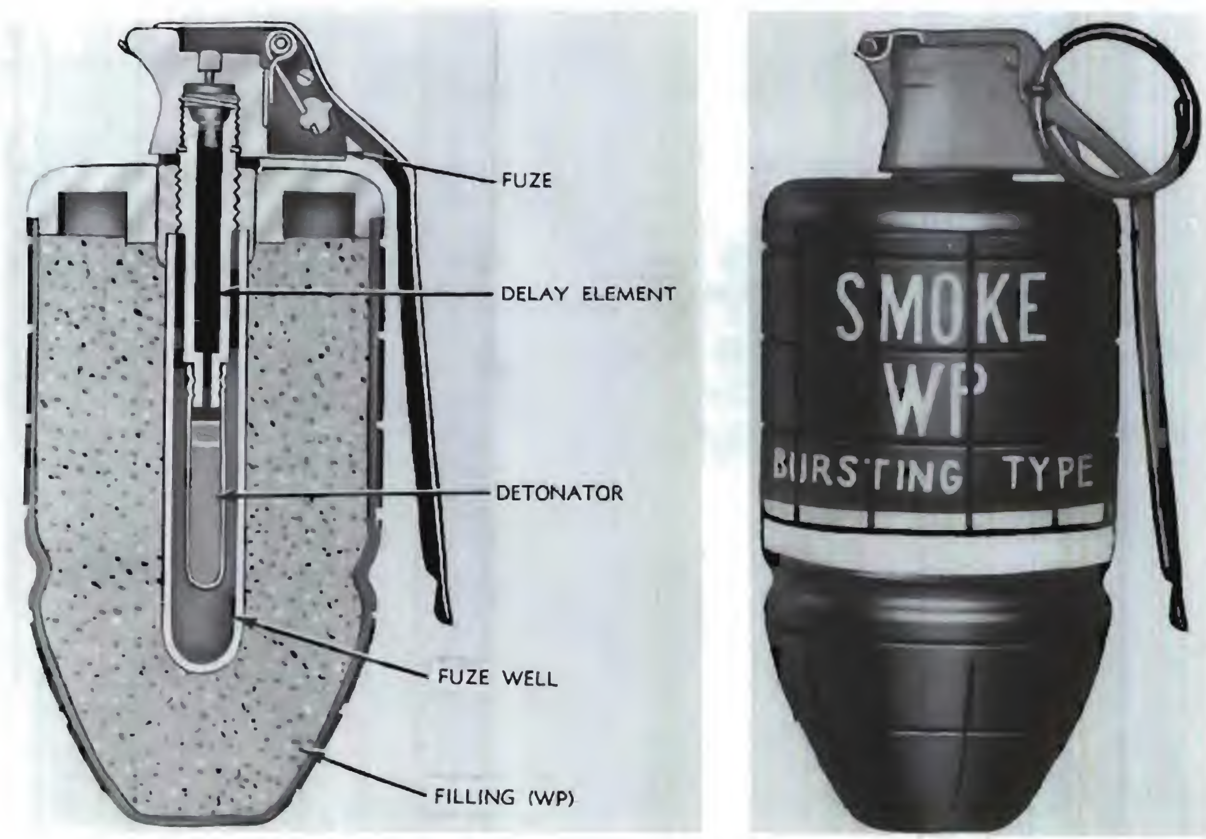

FIGURE 2 — 33(U) — WP SMOKE HAND GRENADE WITH SCORED FRAGMENTING CASING

are covered in pars. 2—9.2.1 and 2—9.2.2, respectively. The WP grenade requires a time delay of 4 to 5 sec because, like the fragmentation grenade, a premature function can cause serious injury to the thrower or to friendly troops.

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CHAPTER 3 (U)

RIFLE GRENADES

3—1 (U) GENERAL

For the purposes of this handbook, a rifle grenade is a grenade that can be fired from a standard infantry rifle. This includes grenades designed specifically for rifle firing (Fig. 3—1) and grenades that can be fired from a rifle by use of a special grenade adapter (Fig. 3—2). Both types are launched by a special auxiliary propellent charge that is loaded into the rifle. Grenades fired from special grenade launchers, and self-propelled grenade-type projectiles are not covered. Furthermore, smoke and illuminating ground signal devices, which resemble rifle grenades very closely and are often fired from rifle grenade launchers, are not covered. These devices, because of their use, are classified as pyrotechnic items[1].

There is at present no requirement for rifle grenades that can be launched from a standard infantryman's rifle M14; however, some of these grenades are still in inventory and can be fired from the M1 rifle. The antitank rifle grenade has been replaced by the 66 mm rocket launcher M72 and the antipersonnel rifle grenade by the 40 mm grenade launcher M79 (see par. 1—4.2). Both of these new weapons are superior to rifle grenades in range accuracy and effectiveness. However, the information given in this chapter is to preserve technical knowledge on the subject, and to be prepared if a unique fighting situation again requires rifle grenades.

3—2 (U) TYPES OF RIFLE GRENADES

The two basic types of rifle grenades in present use, due to an existing inventory, are the high explosive antitank (HEAT) grenade and the chemical smoke grenade adapted to firing from the M1 rifle. The HEAT grenade is used primarily against enemy tanks and armored vehicles, although it may also be used against other types of enemy vehicles and against enemy structures. The chemical smoke grenade is used for signaling and screening. There is no requirement for an antipersonnel (APERS) rifle grenade or for an irritant-type chemical grenade. However, both antipersonnel-type and irritant-type hand grenades can be adapted to firing from the M1 rifle. Furthermore, some foreign nations have developed antipersonnel rifle grenades. For example, the French T32XO rifle grenade[2] is an antipersonnel fragmentation-type grenade designed specifically for rifle firing.

3—3 (U) GENERAL REQUIREMENTS

The general requirements for a rifle grenade are the same as those for a hand grenade (par. 2—2). Specific requirements for each type of rifle grenade are discussed later in this chapter.

3—4 (U) TERMINAL EFFECTS

The required terminal effects for a rifle grenade are strictly defined for the particular type of grenade. Terminal effects, such as the defeat of armor, smoke signals, screening, etc., are discussed later in this chapter. Generally, however, the maximum range of all rifle grenades is limited by the recoil that the soldier and rifle can withstand. If a grenade is fired with the rifle stock resting on the ground (Fig. 3—3), the stock may break if the recoil is too great. If the grenade is shoulder-fired (Fig. 3—3), excessive recoil may injure the firer. These two factors limit the weight, and, therefore, the payload, of a rifle grenade and the maximum range that the grenade can be fired. Operational and test data limit the maximum range of a 1-1/2-lb grenade to about 200 yd. This results in a

FIGURE 3—1(U)—TYPICAL RIFLE GRENADES

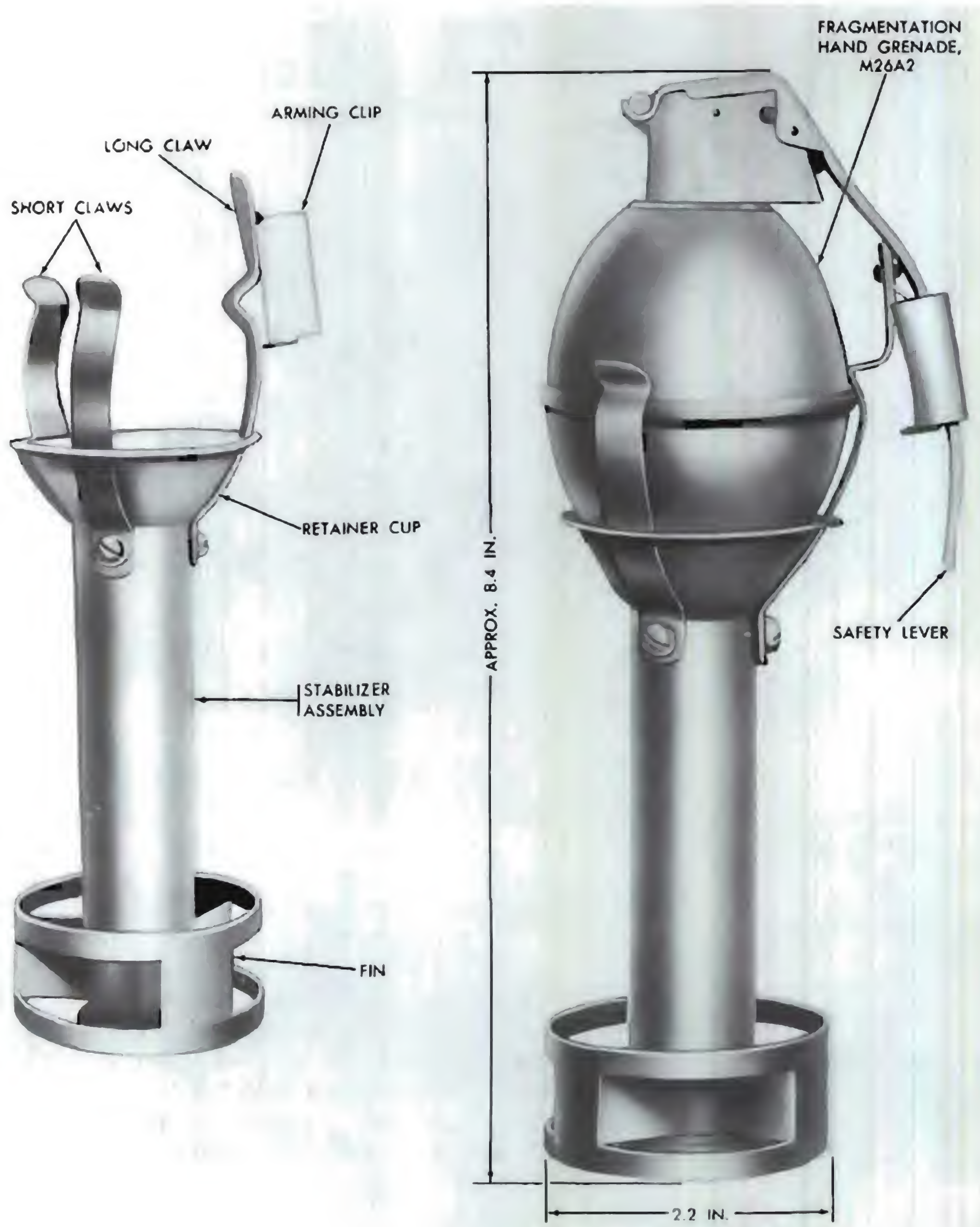

FIGURE 3—2(U)—HAND GRENADE ADAPTED FOR RIFLE FIRING

recoil of about 75 ft-lb which can be withstood by both the firer and the rifle stock.

Other factors besides the strength of the rifle stock and the ability of the firer to withstand the recoil limit the range of a rifle grenade fired by an auxiliary charge to about 200 yd. Attempts to increase the size of the auxiliary charge, and thereby increase the range, can result in any one or more of the following:

a. Breakdown of the cartridge and follower guide in the feed mechanism of the rifle.

b. Breakdown of the rifle trigger mechanism.

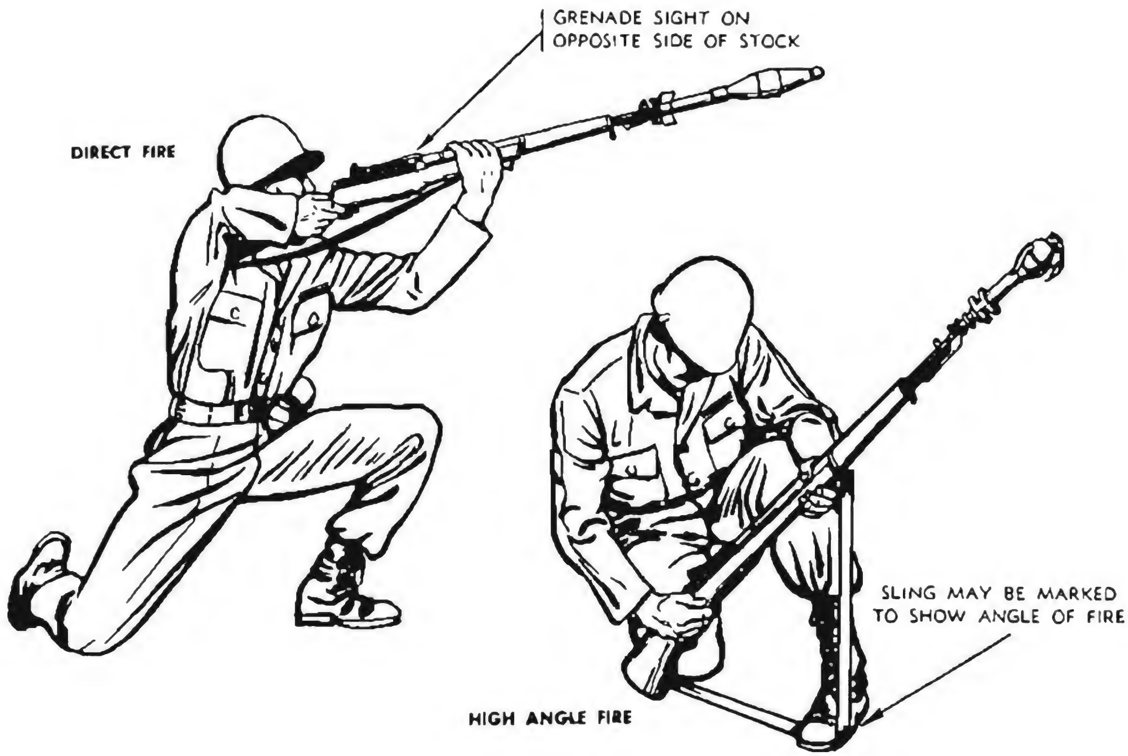

FIGURE 3—3(U)—METHODS OF FIRING GRENADES FROM RIFLES

c. Breakdown of the gas cylinder and relief mechanism in the front part of the rifle.

d. Splitting of the rifle grenade stabilizer.

3—5(U) OPERATION AND ACCURACY

Several operations must be performed to fire a rifle grenade. First, the launcher (Fig. 3—4), and sometimes a special sight (Fig. 3—5), must be attached to the rifle. The launcher is fitted over the rifle muzzle similar to the way that a bayonet is attached to a rifle. The launcher is designed so that its bore is aligned with the rifle's bore. A rifle grenade is then slipped over the launcher so that the tubular section of the grenade stabilizer is locked in place by a retainer spring on the launcher. If a hand grenade is to be rifle-launched, an adapter must first be attached to the grenade, and the adapter slipped over the launcher. The auxiliary charge cartridge

FIGURE 3—4(U)—RIFLE GRENADE LAUNCHER

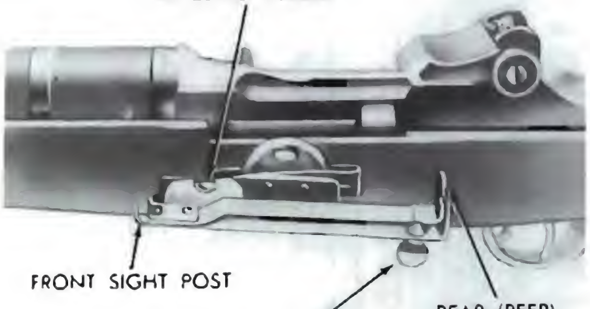

FIGURE 3—5(U)—RIFLE GRENADE SIGHT

is then loaded into the rifle and the rifle is ready to fire.

The required accuracy of a rifle grenade depends upon the type of grenade. Generally, the accuracy of a HEAT rifle grenade must be much higher than that of an APERS or a chemical smoke rifle grenade. The accuracy of an APERS rifle grenade must, in turn, be greater than that of a chemical smoke grenade. The primary reason for this is that the penalty incurred for inaccuracy is greatest for a HEAT grenade and least for a smoke grenade.

Many variables enter into the accuracy of a rifle grenade, and some of these variables are not under the control of the grenade designer. For example, while the aerodynamics of the grenade, the accuracy of the launcher and sight calibrations, and the reliability of the auxiliary charge are under the designer's control; the firer's skill at estimating the range of a target (under stress the range estimation error σ approximates 25% true range) and the speed of a moving target, and the manner in which the rifle is supported when the grenade is fired, are not under the designer's control. The greatest variable is the skill of the firer. Because of the short range of a rifle grenade, the rifle must be fired at some angle above the horizontal after estimating the range to the target. In the case of HEAT grenades, the firer must also estimate the speed of the target before firing. Therefore, considerable training is required to fire a rifle grenade with a high degree of accuracy.

3—6(U) HIGH EXPLOSIVE ANTITANK RIFLE GRENADE

3—6.1(U) GENERAL

The primary purpose of the HEAT rifle grenade is to defeat armored vehicles. It may also be used to defeat other types of hard structures.

The three major factors that must be considered when designing a HEAT rifle grenade are: (1) the type of explosive charge used to defeat armor, (2) the methods of stabilizing the grenade in flight, and (3) the method of fuzing (including safety and arming). Each of these factors is discussed in the paragraphs which follow.

3—6.2(U) SHAPED CHARGES

There are three basic methods — other than mines — of defeating armored vehicles. These are:

1. Penetration of the armor by a kinetic energy projectile. A kinetic energy projectile is basically a solid steel projectile fired at a velocity high enough to provide the kinetic energy required for the projectile to penetrate the target. Typically, velocities of 3000 to 5000 fps are required for this type of projectile. Since rifle grenades achieve a velocity of only 150 fps, they cannot be designed as a kinetic energy-type projectile.

2. Spalling of armor. This method is used to defeat armor without actually penetrating it. By using a high explosive plastic (HEP) filler in a deformable casing, an explosion in intimate contact with the outside of an armor plate can produce sufficient shock to cause a spall on the inside surface of the plate. This spall, which is roughly circular in shape, is projected at high velocity to cause serious damage within the armored vehicle. For proper performance, HEP rounds must strike the target at a higher velocity than can be achieved by

rifle launching. Therefore, HEP rounds are not considered for use as rifle-launched weapons.

3. Penetration of the armor by a high-velocity jet (shaped charge). In this method, a high-velocity jet of metal particles penetrates the armor after the projectile strikes the target; the projectile itself does not penetrate. Unlike armor-piercing projectiles, a shaped charge projectile does not have to strike a target at high velocity to be effective. In fact, it is relatively independent of striking velocity. Therefore, it is ideally suited for use in antitank rifle grenade applications. Shaped charges are discussed further in the paragraphs which follow.

3—6.2.1 (U) Shaped Charge Principles [3]

A shaped charge is essentially a cylindrical explosive with a cavity at one end. A cylindrical explosive with a cavity at one end will inflict more damage on a given material than an equivalent cylindrical explosive without a cavity (Fig. 3—6). The charge with the cavity, although it contains less explosive, produces a deeper hole in the steel block. The deepest penetration will occur when the shaped charge is at a standoff of several cone diameters.

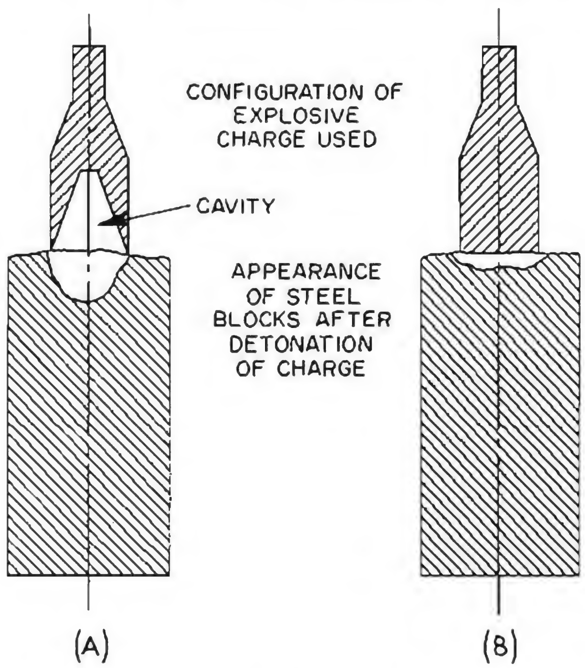

FIGURE 3 — 6(U) — PENETRATIONS PRODUCED BY EXPLOSIVE CHARGES WITH AND WITHOUT CAVITIES

By lining the cavity with some material — e.g., copper — the depth of shaped charge penetration can be increased. However, when a liner is used, maximum penetration occurs when the charge is detonated a short distance from the block, rather than in contact with it. This is because of the behavior of the metal liner as the detonation wave travels through the explosive. When the end of the explosive opposite the liner is initiated, the detonation wave passes over the metal liner, causing the liner to collapse upon itself (Fig. 3—7). When the collapsing liner material reaches the axis of the system, it divides into two parts. A small part forms an extremely high-velocity jet, and the other part forms a slower, but more massive, slug (Fig. 3—7(D)). The high-velocity jet is responsible for the relatively deep penetration achieved by a shaped charge. The tip of the jet attains a velocity of about 25,000 fps, and the rear portions of the jet attain velocities of nearly 5000 fps. This velocity difference within the jet is a result of the physical characteristics of most shaped charges. At the apex of the cone, the ratio of the explosive charge to the liner mass is relatively large. However, as the detonation progresses down the liner, the mass of the liner increases while the amount of explosive available to move it decreases. The ratio goes to zero at the base of the liner because there is no explosive at the base. Therefore, the various portions of the liner reach the axis at progressively lower velocities and generate a jet having a velocity gradient along its length.

Because the jet impacts a target at such high velocities, an exceedingly high pressure is generated. Typically, this pressure is about 4×10^6 psi. The high pressure causes both the jet and the target to deform hydrodynamically. The jet moves the target material radially and flows with it (Fig. 3—8). Penetration continues in this manner until the jet is used up or until the jet decreases to some critical value.

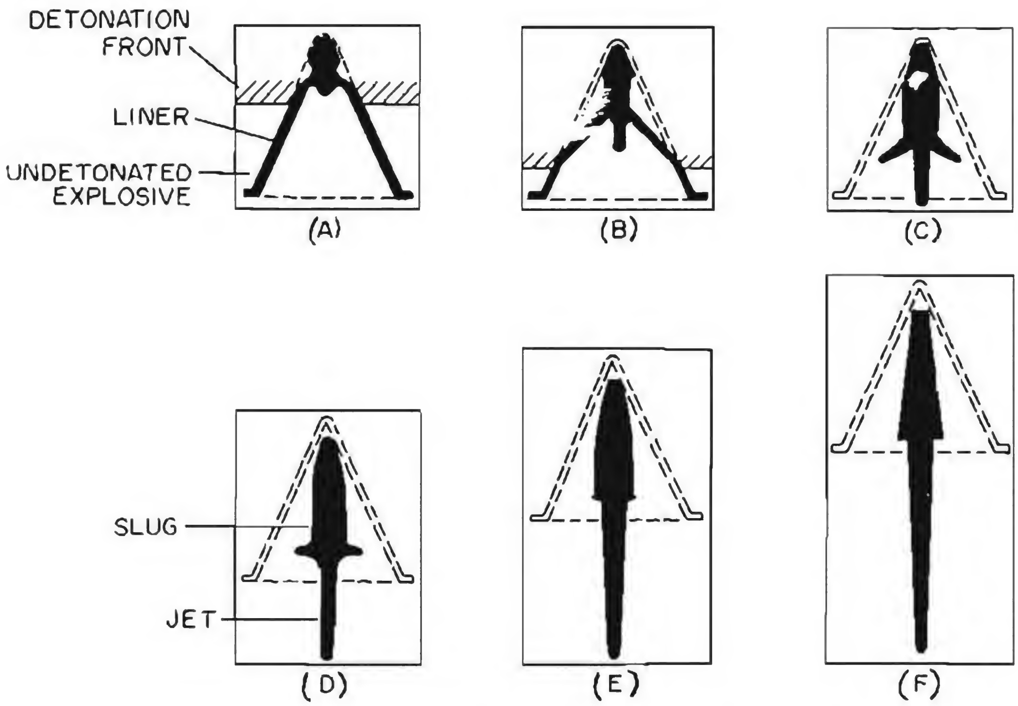

FIGURE 3—7(U)—COLLAPSE OF A SHAPED CHARGE CAVITY LINER

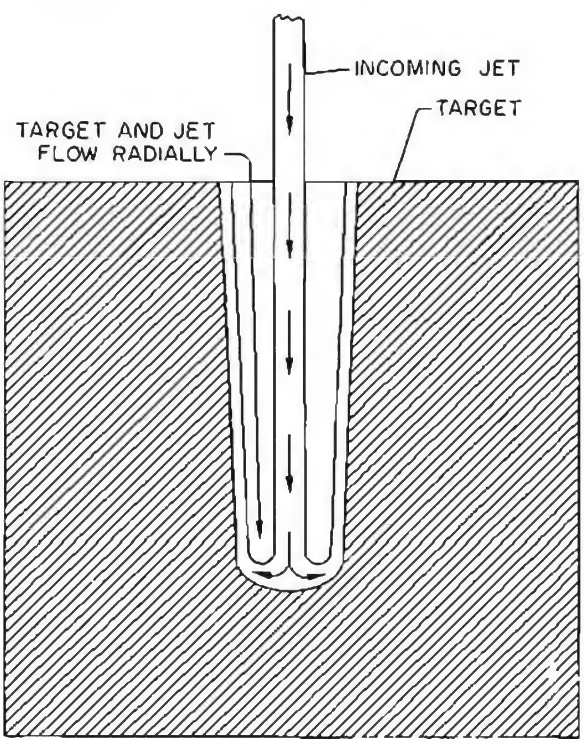

FIGURE 3—8(U)—HYDRODYNAMIC DEFORMATION OF JET AND TARGET [11]

Fig. 3—9 shows a typical HEAT rifle grenade. It contains a high explosive (Composition B) hollowed out in the form of an inverted cone. The cone is lined with copper. Since a shaped charge must be initiated along the axis in the direction towards the target, a point-impact, base-detonating (PIBD) type of fuze must be used. Various types of PIBD fuzes are discussed in par. 2—9. However, the fuzing method shown in Fig. 3—9 appears to be the one best suited to rifle grenades. A piezoelectric (Lucky) element in the nose of the grenade deforms upon impact with the target. The emf developed by the lucky element initiates an electric detonator at the base of the grenade. The rotor rotates the detonator into line only if the grenade achieves a predetermined acceleration.

3—6.2.2(U) Shaped Charge Design

A detailed description of shaped charge design is given in Reference 4. In addition, there are a large number of reports on shaped charge design published by Picatinny Arsenal, Dover, N. J., and the Ballistic Research Laboratories (BRL),

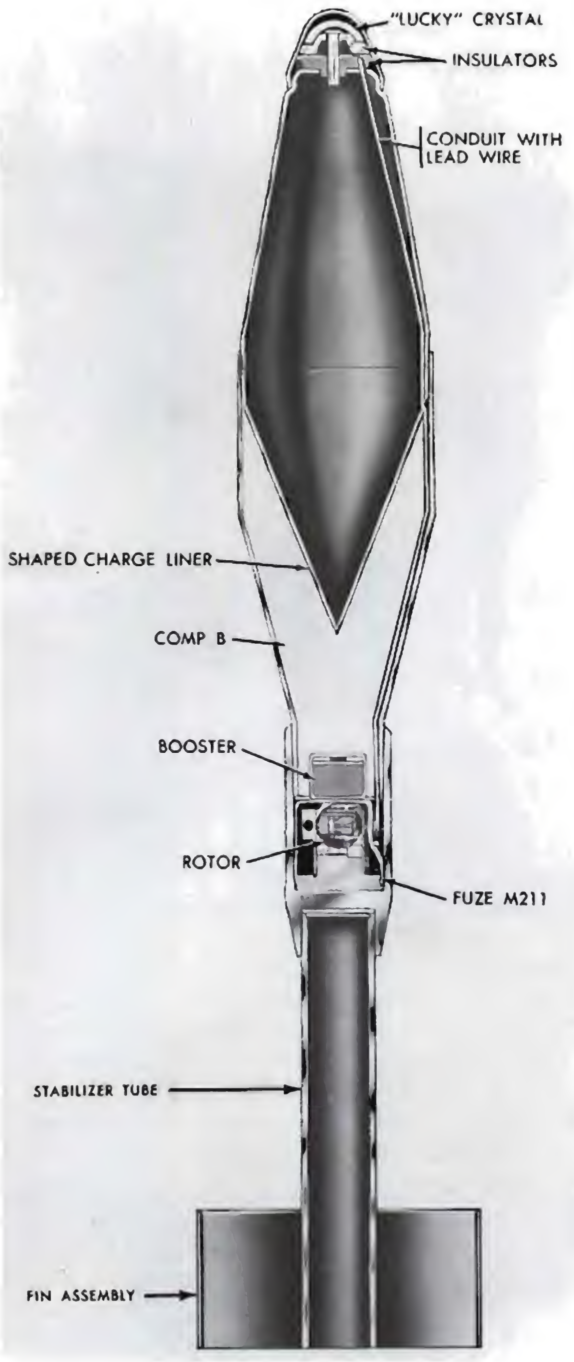

FIGURE 3—9(U)—MAJOR COMPONENTS OF A HEAT RIFLE GRENADE

Aberdeen Proving Ground, Md. General shaped charge design considerations relating to rifle grenades are discussed in the paragraphs which follow.

3—6.2.2.1(U) Charge Characteristics

The length of the grenade body, and hence of the charge, is usually limited by aerodynamic performance considerations and by grenade weight specifications. In general, the penetration and the hole volume obtained increase with increasing charge length. They reach a maximum when the charge length is 2 to 2-1/2 times the charge diameter for heavily confined charges, and when the charge length is about 4 times the charge diameter for lightly confined or unconfined charges.

Existing shape charge designs usually have one of the shapes shown in Fig. 3—10. Although all three designs can be made to perform satisfactorily, each has certain advantages. Design (A) has the advantages of ease of manufacture, higher explosive loading, and blast effect (because of the larger amount of explosive). Designs (B) and (C) are sometimes necessitated by the requirements for aerodynamic configuration and accuracy. Design (B) is the type found most suitable for HEAT rifle grenades.

A longer jet of high velocity can be achieved by using wave forming techniques, i.e., by placing a block of high explosive with a lower detonating rate in the center of the main charge. By doing this, the detonating wave hits the sides of the liner sooner than it reaches the apex, thereby reducing the time required to collapse the entire liner and form the jet. At the present time, however, wave forming techniques

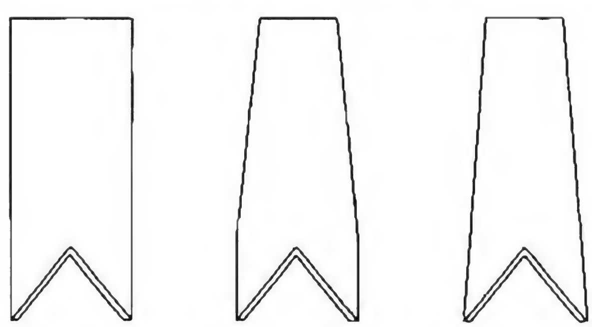

FIGURE 3—10(U)—TYPICAL CHARGE SHAPES

are not considered economically feasible for rifle grenades.

Generally, the effectiveness of the jet is proportional to the detonating rate of the explosive. Since the detonating rate is proportional to loading density, the explosive should be cast as solid as practicable.

3—6.2.2.2 (U) *Liner Characteristics*

Liners of many different shapes have been investigated. To date, however, the most effective and most consistent results have been obtained with conical liners of appropriate apex angle and wall thickness. Practical restraints limit the liner apex angle to between 40° and 60°. Wall thickness is generally about 0.04 in.

The depth of the cavity formed in the target is related to the density of the liner material, as part of a complex relationship with the liner length, type of explosive used, explosive configuration, explosive confinement, amount of explosive, standoff, etc. Both copper and low-carbon steel have been found satisfactory for rifle grenade liners. Since copper is denser than steel, the jet will penetrate further into the target when a copper liner is used. However, the cavity diameter will be smaller when a copper liner is used. Copper liners are more effective against armor, while steel liners are more effective against personnel because they produce fragments. Since a HEAT rifle grenade is designed exclusively to defeat tanks and armored vehicles, a copper liner should be used in the shaped charge.

3—6.2.2.3 (U) *Standoff*

The shaped charge must be initiated before excessive crush-up of the grenade nose occurs. There is an optimum standoff at which the shaped charge is most effective. Standoff distance is determined by the length of the HEAT grenade ogive, the velocity of the grenade, and the fuze function time. The optimum standoff for a conical liner is often four conical diameters or greater. However, the actual standoff distance is usually limited to from one to three cone diameters by aerodynamic considerations involved in ogive shape and size. This range of standoff is adequate to achieve 90 percent of the penetration achieved at optimum standoff.

3—6.3 (U) STABILITY

Accuracy is one of the most important requirements for a HEAT rifle grenade. For the grenade to be accurate, its probable error or standard deviation must be small. For a number of grenades of the same type fired at the same elevation and launcher position, the greater the drag on any one grenade, the shorter will be its range. Thus, for accuracy the drag must be essentially constant for all grenades of the same type. For the drag to remain constant, the grenade must be stabilized so that it always travels nose first.

The two methods of stabilization are spin stabilization and fin stabilization. Although spin stabilization is desirable because of its simplicity and ease of implementation, rifle grenades must be fin-stabilized because of the way that they are launched.

A detailed description of stability design for fin-stabilized projectiles is given in Reference 5. General considerations with respect to rifle grenades are discussed in the paragraphs which follow.

The stability of a grenade in flight is dependent upon the shape of the grenade, its center of gravity, and the location of the center of pressure with respect to the center of gravity. A favorable location of the center of pressure for a rifle grenade can be achieved by mounting fins on the stabilizer tube (Fig. 3—9). If the fins are placed near the rear of the stabilizer tube and are large enough, the lift on the fins will result in the center of pressure of the normal force being behind the center of gravity, thereby ensuring static stability. Because the center of pressure is to the rear of the center of gravity, the overturning moment is negative; therefore, the overturning moment becomes a righting moment and tends to reduce yaw.

Increasing the size of the fins shifts both the center of gravity and the center of pressure towards the rear of the grenade.

Hence, since the total length of the grenade is usually limited, there is a fin size that will maximize the distance from the center of gravity to the center of pressure. For adequate stability, this distance should be at least 10 percent of the total length of the grenade.

The stability of a rifle grenade design can be predicted roughly by using the data given in Reference 5. However, the stability of a grenade can be determined with reasonable assurance only by wind tunnel tests and firing tests.

3—6.4 (U) FUZING

To be effective, a shaped charge must be initiated along the axis in the direction towards the target. Since the grenade strikes the target "nose on," a point-impact, base-detonating (PIBD) fuze must be used. Furthermore, there is an optimum standoff distance at which detonation should occur (par. 3—6.2.2.3), and, therefore, the shaped charge must be initiated before excessive crush-up of the grenade nose occurs. Typically, the nose should not collapse more than about 1/4 in. before initiation of the shaped charge. Therefore, although a rifle grenade is considered a low velocity projectile, a fuze capable of initiating the shaped charge in a matter of microseconds is required. For example, a rifle grenade travels about 150 fps. On the assumption that the nose is permitted to collapse 1/4 in. before the shaped charge is initiated, then the time available from nose impact to shaped charge initiation is 140 μ sec. This is a relatively short time for mechanical fuze action to occur.

Mechanical methods and electrical methods of transmitting information from the nose to the rear of the grenade have been investigated. Both types are discussed in the paragraphs which follow.

3—6.4.1 (U) Mechanical Fuzing Methods [5]

Two basic mechanical fuzing methods have been investigated to transmit information from the nose to the rear of a rifle grenade. One method employs a so-called "spit-back" or "flash-back" fuze. In this type of fuze, a small shaped charge explosive in the nose of the grenade is initiated by a percussion primer upon impact with the target (Fig. 3—11). The shaped charge fires a jet rearward through a passage provided in the main charge into a base booster charge which initiates the main charge. Since the velocity of a shaped charge jet is very high (par. 3—6.2.1), the triggering action caused by nose impact is transmitted very quickly to the rear of the grenade.

This method, although it results in a shaped charge initiation very quickly after grenade impact, depends upon a clear path from the shaped charge in the grenade nose to the booster in the rear. This condition is not always satisfied because parts of the grenade, and particular parts of the fuze, sometimes become misaligned or deformed upon grenade impact. Therefore, this fuzing method is no longer considered for use in HEAT rifle grenades.

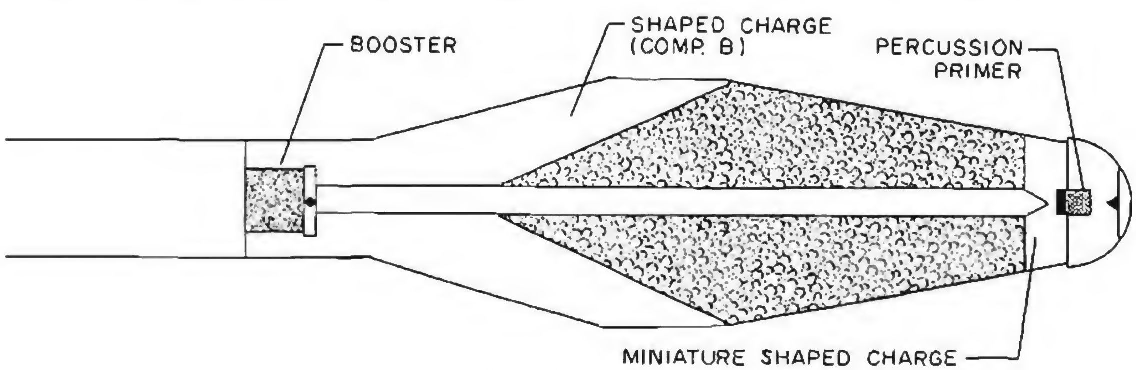

FIGURE 3—11(U)—BASIC PRINCIPLE OF SPIT-BACK FUZE

The second mechanical fuzing method makes use of grenade deceleration upon impact with the target. A firing pin, which is backed by a mass of high inertia, is mounted in the rear of the grenade (Fig. 3—12). The grenade decelerates when it strikes the target, and the firing pin slides forward and fires the percussion primer.

This type of fuze is inherently slow-acting. Furthermore, the grenade must have a very rigid nose section so that the nose will not collapse before the shaped charge is initiated. Because of these disadvantages, this method of fuzing is not used in present-day rifle grenades.

3—6.4.2 (U) Electrical Fuzing Methods

Various methods of electrical contact fuzing that appear applicable to HEAT rifle grenades are discussed in the paragraphs which follow. Of the methods discussed, however, only piezoelectric-type fuzing has been seriously considered and developed. The piezoelectric-type PIBD fuze is preferred for HEAT grenades because it can provide a response rate within practical grenade size, weight, and geometry. All of the other methods have certain limitations that make them inferior to piezoelectric fuzes with respect to effectiveness, reliability, ease of manufacture, and cost.

3—6.4.2.1 (U) Piezoelectric Fuzing

A piezoelectric fuze consists basically of a piezoelectric element connected in series with an electric detonator. When a rifle grenade strikes a target, the piezoelectric element deforms, thereby generating sufficient electrical energy to fire the detonator. A separate power source is not needed since the deformation of the piezoelectric element, itself, produces the required electrical energy.

Since the energy developed by the piezoelectric crystal is typically only a few hundred ergs, detonators used in rifle grenades must have a very high sensitivity. For this reason, a film-bridge detonator is used in present-day rifle grenades. A detonator of this type, using graphite as the bridge material, can be designed with a sensitivity of less than 100 ergs. Design considerations for film-bridge detonators are given in Reference 6. Input requirements and other data for various types of film-bridge detonators are given in Reference 7. When determining the input requirements for a detonator, however, the designer should keep in mind that grenade impact with a target will not always be "nose-on." Rifle grenades often strike the target obliquely, and as the angle of obliquity increases, the electrical energy developed by the piezoelectric element decreases. For example, a flat piezoelectric element that produces 300 ergs upon nose-on impact may produce only 2 or 3 ergs upon impact at a 60° angle of impact. By using a curve-shaped piezoelectric element, performance at oblique angles is improved (Fig. 3—13).

Since a HEAT rifle grenade requires a PIBD fuze, the piezoelectric element is mounted in the nose of the round and the detonator in the rear (Fig. 3—13). Piezoelectric elements of barium titanate have

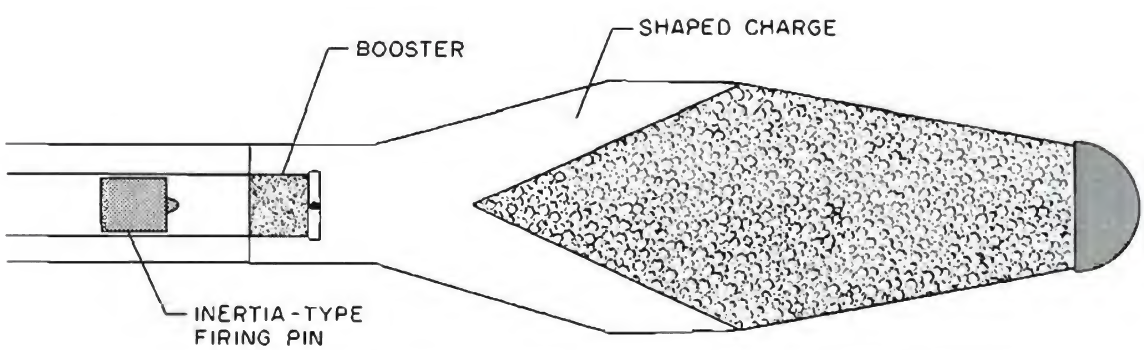

FIGURE 3 — 12(U) — BASIC PRINCIPLE OF INERTIA-TYPE FUZE

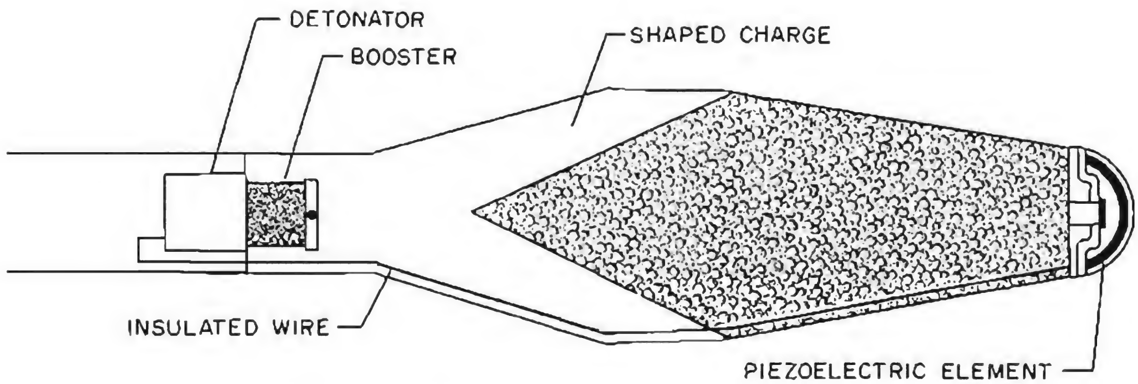

FIGURE 3—13(U)—BASIC PIEZOELECTRIC-TYPE FUZE

proven satisfactory for rifle grenades. Both sides of the element are silver-coated to form electrodes, and an electrical connection is brought out from each side. Usually, one side is grounded, and the other side connected by an insulated wire to the detonator.

Care must be taken when installing the element so that it is not mounted under stress. Since a barium titanate element possesses capacitance, any charge resulting from mounting stress will be stored by the element. Furthermore, stresses resulting from setback at the time the grenade is launched may cause a charge to be developed and stored. A third factor, heat, — which can produce stresses in the element, — may also cause a charge to be stored. To overcome this problem, a bleeder resistor is normally connected across the barium titanate element to dissipate any charge that might accumulate as the result of stress. The value of the bleeder resistor must be high enough to ensure that most of the energy resulting from impact is delivered to the detonator. Typically, a resistor of about 1 megohm is satisfactory. A detailed discussion of piezoelectric elements is given in Reference 8.

3—6.4.2.2(U) *Inertia Generator-type Fuzing*

Inertia generator-type fuzing systems have been investigated for contact fuzing applications. This type of fuze consists essentially of a magnet encircled by a coil of many turns of fine wire. When a round strikes the target, the magnet is ejected very rapidly from within the coil, thereby inducing a high voltage in the coil. This voltage could, in turn, be used to initiate an electrical detonator.

3—6.4.2.3(U) *Proximity Fuzes*

At first glance, certain types of proximity fuzes, — such as capacity fuzes[9], magnetic fuzes[10], and, perhaps, electrostatic fuzes[10] — might appear feasible for use in rifle grenades. All of these fuzes are capable of initiating detonation within a few inches to a few feet of a target. However, these fuzes, in addition to being much more complex and expensive than a piezoelectric fuze, have other operational limitations as discussed in References 9 and 10. Therefore, they have never been considered for use in rifle grenade applications.

3—6.4.3(U) Safety and Arming

Safety and arming considerations are discussed in par. 2—9.2.1. In that paragraph, it was stated that a mandatory requirement for all fuzes is that they must be detonator safe, but that the requirement has been waived for hand grenades because they experience no unique forces that may be used for arming. However, a HEAT rifle grenade, because it does experience unique forces when it is launched, must employ a fuze that is detonator safe. A simple and reliable way of achieving a detonator safe condition is to use an out-of-line detonator (Fig. 3—14). In the safe position, unintentional initiation

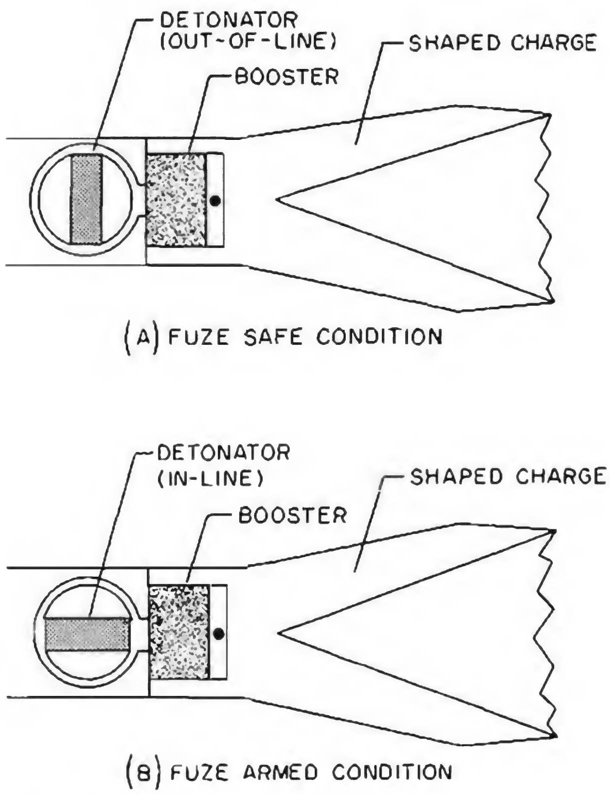

FIGURE 3—14(U)—SIMPLE OUT-OF-LINE DETONATOR

of the detonator cannot initiate the booster, and, subsequently, the main charge. The booster charge, and, consequently, the main charge, can be initiated only when forces associated with grenade launching cause the detonator to rotate into line.

A rifle grenade experiences a fairly large, short-time acceleration at launch. Typically, this acceleration ranges between 500 and 1000 g, depending upon the propelent charge and the launcher setting. Devices operated by setback forces resulting from this acceleration can be used to arm the fuze, i.e., to rotate the detonator into line. However, the fuze should not be designed so that it arms simply because the grenade experiences a specified acceleration. Instead, it should arm only when it experiences a specified acceleration over a specified period of time. There are two reasons for this, namely:

(1) the setback forces resulting from grenade launching might be duplicated during rough handling and transportation, thereby causing the fuze to arm. For example, this might occur during aerial delivery should a parachute fail to open.

(2) if the fuze is designed to arm upon experiencing setback only, the grenade will become fully armed at launch, or a brief instant thereafter, which is considered unsafe by U.S. standards. The fuze must not become fully armed until the grenade has traveled a safe distance from the launcher; typically, about 10 to 20 yd.

Various types of arming mechanisms are capable of providing this delay after launch. For example, an inertial weight that moves at setback can allow a simple escapement timer to rotate the detonator into line. Or, a sequential events setback mechanism (setback leaves) which monitors acceleration time during launch and an escapement timer — e.g., the T1022 series fuze — may be used. Methods of designing these mechanisms, and other applicable mechanisms, are described in References 11 and 12. No matter which type of mechanism is used, it should be reversible, i.e., if a round experiences a very brief acceleration shorter than that specified for arming, the fuze should not remain in a partially armed state. It should, by itself, revert to the completely unarmed state.

3—7 (U) CHEMICAL RIFLE GRENADES

The only chemical rifle grenades in present use are smoke-type grenades. There is no requirement for a riot-type or incendiary-type grenade designed specifically for rifle firing. However, both of these types may be fired from the M1 rifle by use of a special grenade adapter.

The two basic types of smoke rifle grenades are the streamer-type and the impact-type. A streamer-type smoke grenade is designed to issue smoke from the start of its trajectory until it reaches its maximum range, which is about 200 yd. Most impact-type smoke grenades are designed to ignite and burn upon striking the ground at the end of their trajectory. However, the white phosphorous white smoke bursts at impact and releases the smoke as a cloud within a second or so after impact (par. 3—7.2.2.2).

3—7.1 (U) SMOKE COMPOSITIONS

Smoke grenades must produce a smoke of distinct color that is recognizable from various positions in relation to the sun and under various daytime atmospheric conditions. To be tactically useful, the grenade must burn for about 1 minute, and the smoke must be identifiable from a distance of one-half mile on a clear day.

Three colors of smoke, — red, green, and yellow, — are generally considered for use in smoke rifle grenades. The compositions of these smokes are given in Table 3—1 for streamer-type grenades and in Table 2—13 for impact-type grenades. The tables also give the composition of violet-colored smoke, but this smoke, because its visibility characteristics are poor at long distances, is not used in any present-day grenade.

White smoke is also used in smoke grenades. This type of grenade uses white phosphorous as the agent.

3—7.2 (U) DESIGN CONSIDERATIONS

3—7.2.1 (U) Stability

Aerodynamic considerations involved in designing a stable smoke rifle grenade are the same as those for a HEAT rifle grenade, and are discussed in par. 3—6.3. In general, the requirements for a smoke rifle grenade, particularly one of the streamer-type, are not as stringent as those for the HEAT rifle grenade, particularly with respect to accuracy.

3—7.2.2 (U) Fuzing

Methods of initiating streamer-type and impact-type smoke rifle grenades are discussed in the paragraphs which follow. Both the burning-type and the bursting-type impact grenades are discussed.

3—7.2.2.1 (U) *Streamer-type Smoke Grenade*

A streamer-type smoke grenade, in a sense, does not require a fuze, although the device used to initiate the smoke mixture can be referred to as a fuze. Actually, the propellant gases produced by the propellant cartridge are used to ignite the mixture. As shown in Fig. 3—15, the propellant gases pass through a baffle to reduce the force. The gases then pass through a hole in the "fuze" body and ignite a pellet of ignition powder. The ignition powder, in turn, ignites the smoke mixture.

TABLE 3—1(U). STREAMER-TYPE SMOKE GRENADE COMPOSITIONS

SMOKE MIXTURE	*			
	Green	Red	Yellow	Violet
Dye	156	122	149	122
Potassium Chlorate	116	143	89	143
Sucrose	116	143	68	143
Potassium Bicarbonate	20			
		Press at 3000 psi (min)		
IMPREGNATING MIXTURE	*	STARTER MIXTURE		*
Potassium Nitrate	152	Potassium Nitrate		417
Charcoal	65	Silicon		309
Gum Arabic (dissolved in water 8:92)	9	Charcoal		46
		Binder:		
		Nitrocellulose		13
		Acetone		317

* Parts by weight

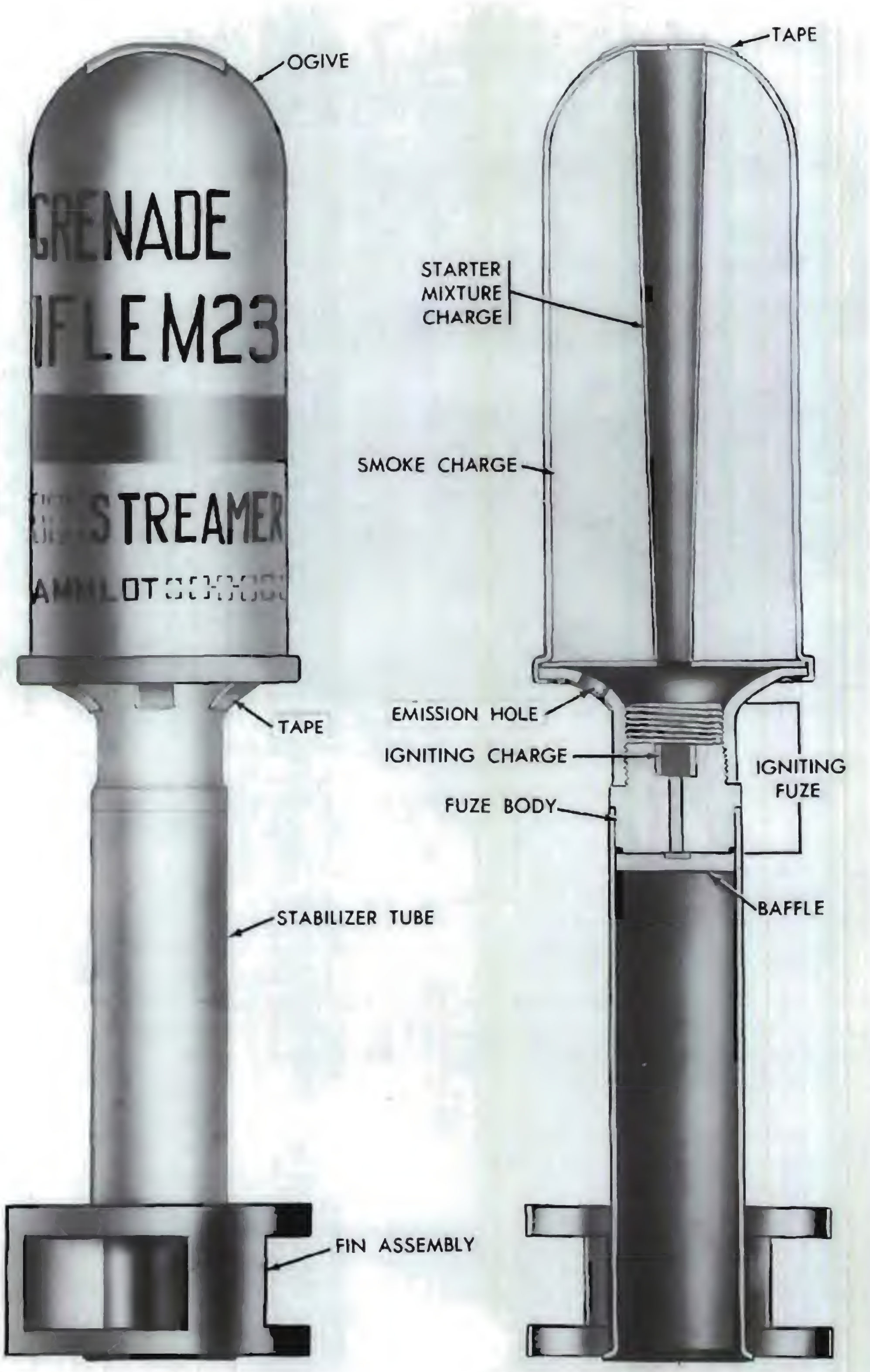

FIGURE 3—15(U)—STREAMER-TYPE SMOKE GRENADE

Since a streamer-type grenade actually has no fuze, it requires no arming mechanism. Safety is inherent because the forces required for initiation, i. e., the propellant gases, can only be present when the grenade is launched from the rifle. They cannot be duplicated in transportation and handling.

3—7.2.2.2 (U) Impact-type Smoke Grenade

Inertia-type impact fuzes have proven satisfactory for impact-type smoke grenades. For a grenade that burns after impact, this type of fuze consists essentially of a high-inertia firing pin, a creep spring and a simple safety device (Fig. 3—16). When the grenade strikes the ground at the end of its trajectory, the firing pin, because of its inertia, is driven into a stab primer. The primer, in turn, ignites the smoke mixture.

A creep spring must be placed between the firing pin and the primer to prevent the firing pin from moving forward as the grenade decelerates due to air resistance.

As air resistance causes the grenade to decelerate in flight, there is a tendency for the firing pin to move forward (creep). If this movement is not restrained, the distance between the firing pin and primer may be reduced to a point where the firing pin cannot acquire sufficient energy to initiate the primer. The simplest way to overcome firing pin creep is to place a spring between the primer and the firing pin. Methods of determining creep forces, and of designing a spring to resist them, are given in Reference 12.

Arming safety for this type of rifle grenade can be provided simply by locking the firing pin with a device that is removed by hand just prior to launching the grenade. A safety pin or wire that passes through the firing pin and locks it in place is generally used. This pin or wire can be attached to a clip that is snapped off by hand just prior to launch, which simplifies removing the pin or wire (Fig. 3—16). However, some additional safety is provided by making the pin or wire more difficult to remove, as shown in Fig. 3—17.

The fuze, and safety and arming for a bursting-type impact grenade (WP) is essentially the same as that for the burning-type, except that it requires a detonator to open the casing and disperse the filler. A detonator of the same size and type as an ordinary blasting cap has proven satisfactory for this purpose.

3—8 (U) PROPELLANT CHARGES

Rifle grenades are projected from a rifle by special blank cartridges. The use of service ammunition, such as ball or AP ammunition, is **ABSOLUTELY PROHIBITED**, since it will most likely detonate the grenade, killing the firer. In the past, attempts have been made to design grenades that can be fired by service ammunition. This was done to eliminate the hazard of inadvertently using service ammunition rather than special blank cartridges. Grenades of this design contained a central hole that "caught" the bullet, and were referred to as bullet "catchers." For various reasons, such as the need for a very rugged grenade to withstand bullet impact and the difficulty of designing a reliable and safe grenade, the design of bullet-catcher rifle grenades has been abandoned.

Some foreign rifle grenades are launched with special cartridges having frangible bullets of wood or plastic. However, these cartridges resemble ball ammunition, making identification in the dark difficult. Thus, this increases the possibility, and the hazards, of launching a grenade with the wrong ammunition.

The use of special blank cartridges (Fig. 3—18) to launch grenades from an infantryman's rifle is a standard requirement for U. S. grenades. The cartridge charge is limited in size by the rifle chamber; the amount of the charge is governed by the weight of the grenade and the recoil that the firer and the rifle, itself, can withstand.

The 7.62 mm M64 cartridge is loaded with 40 grains of IMR 4895, or 37 grains of HPC 4, or 45 grains of WC 830.

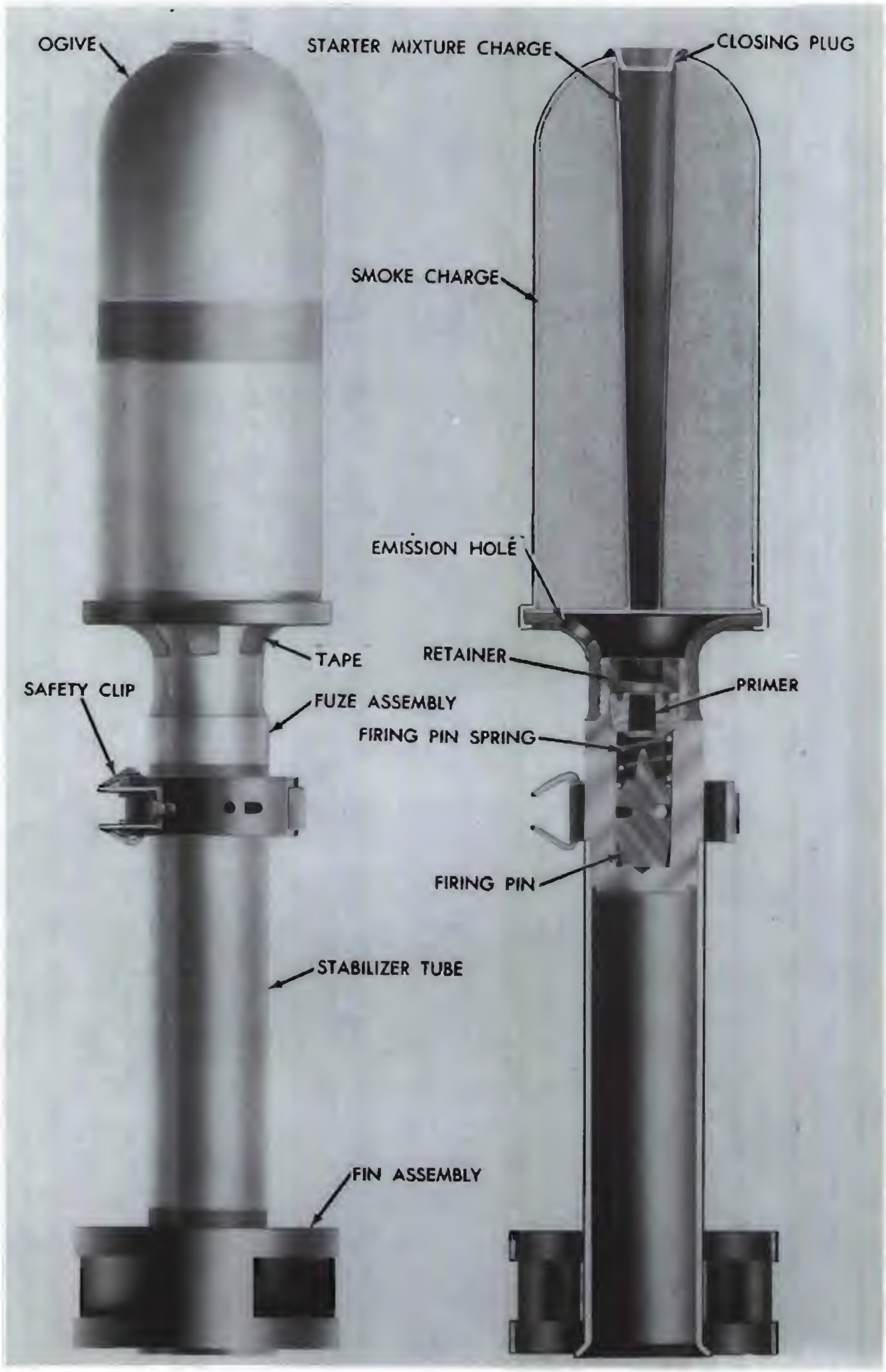

FIGURE 3 — 16(U) — BURNING-TYPE IMPACT SMOKE GRENADE

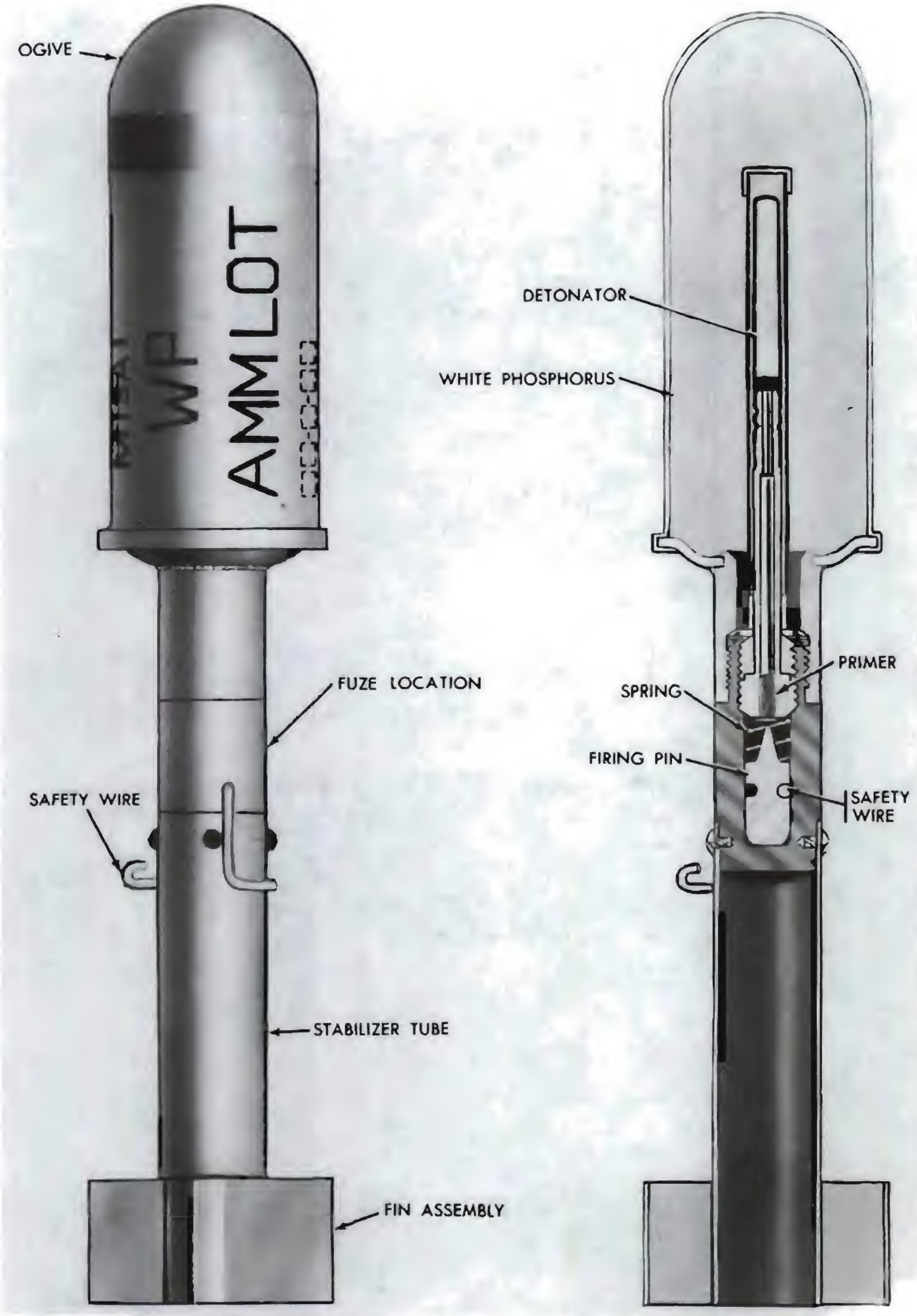

FIGURE 3—17(U)—BURSTING-TYPE IMPACT SMOKE GRENADE

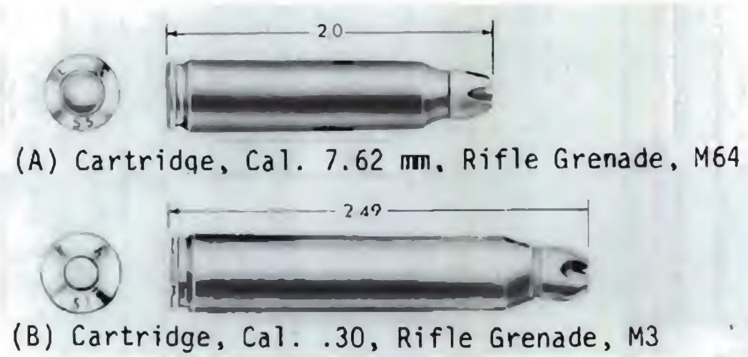

FIGURE 3—18(U)—CARTRIDGES FOR RIFLE GRENADES

The cal. 30 M3 cartridge is loaded with 40 grains of IMR 4895 and 5 grains of A-4 black powder.

In cases where very light grenades are to be launched, the charge may be increased by adding an auxiliary charge container in the base of the round so that it will be ignited by the blank cartridge when the rifle is fired.

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CHAPTER 4 (U)

TRAINING AND PRACTICE GRENADES

4—1 (U) GENERAL

Various types of grenades are required to train personnel in the handling and use of service grenades. These grenades must simulate service grenades as closely as possible. However, they must be safe for use by personnel undergoing training and by instructors conducting the training.

The paragraphs which follow discuss design considerations for training grenades and practice grenades. A third typ : of grenade, called a simulated grenade, is not covered. This type is used simply to simulate a grenade burst during battle maneuvers, and is classified as a pyrotechnic item[1]. It more closely resembles a firecracker rather than a grenade.

4—2 (U) TRAINING GRENADES

Only fragmentation-type hand grenades require a training counterpart. Unfilled service hand and rifle chemical grenades may be used for training with little or no hazard. Practice-type HEAT rifle grenades (par. 4—3) can also be used as training grenades.

A training grenade must be inert, i. e., it must contain no explosives or pyrotechnic of any kind. Its primary purpose is to give the trainee the same "feel" as its service counterpart. Therefore, it should conform as closely as possible to the size and weight of the service grenade, and should possess the same types of arming features. It can be loaded with sand or similar material to simulate the weight of the explosive charge. Since the grenade must be handled and thrown over and over, it must be as durable as practicable.

A typical training grenade is shown in Fig. 4—1. It can be compared with its service counterpart, the MK2, which is shown in Fig. 2—6.

FIGURE 4 — 1 (U) — TRAINING HAND GRENADE

4—3 (U) PRACTICE GRENADES

Only fragmentation-type hand grenades and HEAT-type rifle grenades require practice counterparts. Unfilled service hand and rifle chemical grenades may be used as practice grenades. Furthermore, service chemical grenades, themselves, except for those containing white phosphorous, can be used for practice with little hazard.

4—3.1 (U) PRACTICE HAND GRENADE

A practice hand grenade differs from a training hand grenade primarily in that it

contains a small explosive charge to simulate detonation. Safety is the primary consideration in designing the practice grenade. A major requirement is that the explosive charge must not be great enough to break the grenade casing. This eliminates the danger of trainees being struck by fragments.

For simplicity and cost, practice grenades generally use black powder as the explosive charge. Black powder produces a reasonable amount of white smoke and a fairly loud report. By confining the powder, and by adding about 10 percent of flaked aluminum to the charge, the brisance of the explosion, and, therefore, the loudness and sharpness of the report, can be greatly increased.

For economy, practice grenades should be designed for reloading and reuse. To accomplish this, the grenade body must be rugged enough to withstand not only repeated impacts but also the repeated explosions of the practice charge. Ideally, the grenade should be designed so only a replacement explosive cartridge need be inserted after each use.

A typical practice grenade is shown in Fig. 4—2. Its service counterpart is the Mk2 fragmentation grenade shown in Fig. 2—6. It consists of a cast iron Mk2-type grenade body fitted with the standard fuze for the Mk2 grenade. However, in place of a detonator, a black powder igniter in a gilded metal case is used. A small charge of black powder in a cloth bag supplements the igniter charge. A loading hole in the base of the casing allows the grenade to be reloaded with explosive charge.

4—3.2 (U) PRACTICE RIFLE GRENADE

A practice rifle grenade provides practice in handling and firing a particular type of service rifle grenade. A practice rifle grenade does not contain any explosive charges; therefore, it can also be used as a training grenade.

Rifle grenades are subject to a great deal of abuse, and therefore must be exceptionally rugged if they are to be used repeatedly. The stabilizer assembly of a practice rifle grenade is particularly prone to damage by repeated firings. Therefore, it is desirable to design a practice grenade

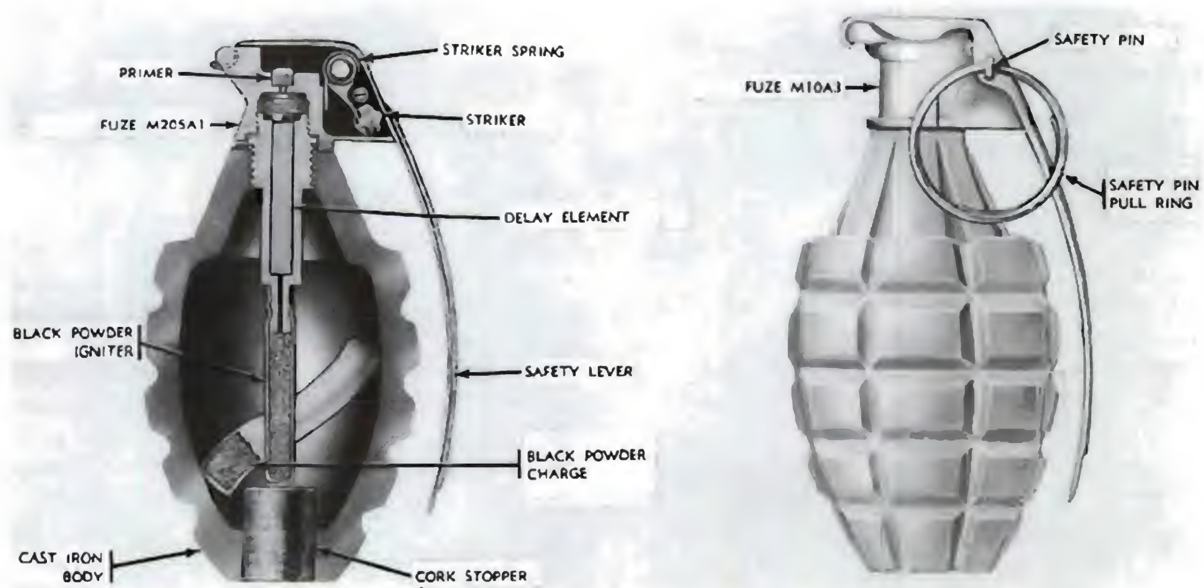

FIGURE 4—2 (U)—PRACTICE HAND GRENADE

so that the assembly is replaceable. Replacement procedures should be simple enough to be carried out in the field without the use of special tools. For example, the fins of the T44 Practice Rifle Grenade can be removed simply by rotating them 90 degrees, by hand. Replacement fins can be installed by slipping them onto the stabilizer tubing and twisting them 90 degrees, by hand, to lock them in place[2].

Fig. 4—3 shows a typical practice rifle grenade. It conforms to its service-type counterpart in shape, weight, and ballistic characteristics. The body is made of cast iron, and the stabilizer assembly is replaceable.

Practice rifle grenades can also be made with solid rubber bodies. These can be used against operational vehicles, with little risk of damaging the vehicles. However, it is usually more difficult to manufacture rubber-type grenades to match the characteristics of their service-type counterparts.

FIGURE 4—3(U)—PRACTICE RIFLE GRENADE

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